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MECHANICAL AND ELECTRONIC EVALUATION
OF TWO COMMONLY USED POLYGRAPH INSTRUMENTS

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Physical Psychology Branch
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Office of Naval Research
Department of the Navy
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— 1 —

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John C. Stetson

John C. Stetson
The Southern Instrumentation Co.

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ATTACHMENT 1

EVALUATION OF CARDIOGRAPH AND PNEUMOGRAPH
SECTIONS OF TWO POLYGRAPHS

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EVALUATION OF CARDIOGRAPH AND PNEUMOGRAPH
SECTIONS OF TWO POLYGRAPHS

The evaluation of two commercial recording lie detectors was accomplished by applying known pressure signals to the inputs of the "Cardio" and "Pneumo" systems. Separate tests were performed on the chest expansion bellows which were calibrated in a freely suspended position.

The two instruments tested were a "Deceptograph" model 22500, case number BB 49654, manufactured by C. H. Stoelting Company, Chicago, Illinois and a "Keeler" polygraph, model 6303, serial number 569, manufactured by Associated Research, Chicago. The instruments shown in figures 1A and 1B were received in new condition from the Office of Naval Research. Tests were divided into two sections: static and dynamic. Test data were obtained in the form of traces on the chart recorder which is an integral part of each polygraph and were read from the chart grid as they would be in actual use. No corrections were made for errors introduced by use of rectilinear chart to read out curvilinear deflections.

1. STATIC TESTS ON POLYGRAPHS

1.1 General Considerations

Prior to the tests, the polygraphs were inspected visually and set up for operation according to the manufacturers' instructions. This included attachment of all hoses, insertion of record paper, placement of inkwell, filling of inkwell, checking of pens, checking of lockbars in "Cardio" system, balancing of pens. Finally the systems were checked for leakage rate.

For the "Stoelting" polygraph, the inkwell was found to be difficult to insert, the lockbar in the "Cardio" channel did not hold at all pressures. For the "Keeler," one of the pens was found to have a lot of friction in its pivots (it was replaced), and the inkwells were found difficult to fill.

1.1.1 Pen Pressure

On both instruments, pens are equipped with counter weights. The positions of the weights determine pen pressure, and therefore influence recording characteristics. Manufacturers instructions for the "Keeler" read: "Balance the pens for minimum weight on chart for maximum pattern. This is done by turning counterbalance nuts behind pen pivots so that the nut moves away from the pivot. If the nut is turned too much, the pen may rise off the chart or start floating. If that happens, merely screw the nut back toward the pivot a few turns."

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For the "Stoelting", the instructions read, in part,: "An extremely light touch of pen tip, consistent with continuous writing is desired to minimize friction on the chart surface. To adjust: Move the hexagon counterweight in or out on the threaded shaft".

Test were run with weights in two position for "light pen" and "heavy pen". The light pen position is achieved by adjusting the position of the counterweights so that when the pen tip is raised a quarter inch and released, the pen point will return to touch the paper in ten consecutive trials, but will not return consistently when it has been raised one half inch. The "light pen" condition is the one which is expected to give optimum recording results. During use of the polygraph to achieve the "heavy pen" condition, for evaluation purposes, the counterweight is screwed in as far as it will go toward the pivot arms.

During the tests, two factors were found which should be considered during the actual use of the polygraph. The pens require cleaning each day (or whenever the polygraph has not been used for several hours). During cleaning, the counterweights may tend to rotate on the threaded shaft and may thus be inadvertently changed in position. To assure optimum pen pressure, the counterweight position should be checked (and re-adjusted when required) whenever the pens are cleaned. Lock nuts would prevent accidental changes in counterweight position.

1.1.2 Leakage Tests

Leakage tests were performed first to assure the operational integrity of the whole system. In these tests a constant pressure was applied to the system causing a deflection of the pen. The system was then isolated from the source of pressure and a record taken over a period of time. Leakage from the system would be disclosed by a gradual, continuing change in pen position in the direction corresponding to decreasing system pressure. Pen movement in the opposite direction might indicate the existence of "Creep" (The gradual change in dimensions of a material under a constant stress)

Early tests on the "Cardio" system showed a gradual trace shift in the direction of decreasing pressure, indicating a possible leak. Additional tests made by first increasing pressures above the desired operating point, then decreasing it to the steady operating value prior to source isolation showed a gradual pressure increase. Further tests on this system performed in a similar manner but with a ten minute delay between initial pressure application and trace monitoring (recording) showed no noticeable trace shift during a two

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minute monitoring period. If a leak had been present, the trace would have continued to shift in the direction of decreasing pressure even after the ten minute delay.

Anomalous behavior was not noticed during leakage tests on the "Pneumo" system, where the pressures are generated by small deflections of the chest expansion bellows, which produce much lower pressure levels than those in the "Cardio" systems. Results of leakage tests on the "Pneumo" systems were not changed by elimination of the ten minute delay.

1.1.2.1 Leakage Test on "Cardio" Systems.

Leakage tests for the "Cardio" systems of the polygraphs were carried out by pressurizing the systems, isolating the pressure source, then a ten minute delay followed by two minute of recording. For the "Stoelting", no leakage was observed at a system pressure of 50 mm of mercury, a drop in pressure of less than 1 mm Hg in two minutes was observed at 100 mm Hg and 150 mm Hg.

Initial tests on the "Keeler" showed the presence of a small leak which was traced to the hand pump bulb. Subsequent tests with the bulb excluded indicated no leakage at 60 mm of mercury and a leakage rate of less than 0.5 mm of mercury in two minutes at pressures of 90 mm and 120 mm of mercury. Tests were limited to these pressures because of a warning in the instruction book of the "Keeler" "...not to inflate over 140 mm of pressure as physical damage to the Cardio tambour may result."

1.1.2.2 Leakage Tests on "Pneumo" Systems

Leakage tests for the "Pneumo" system of the "Stoelting" polygraph were run with two deflections of the chest expansion bellows. The bellows were suspended vertically in a special fixture built for the deflection calibration of the bellows. With the bellows freely suspended, the system vent was opened to equalize pressure and then closed. The bellows were extended one half inch and after a ten minute delay, the chart motor was turned on.

The pressure was monitored during a two minute period (as for the "Cardio" system, above). For the second test, the bellows were extended 6 inches, the system pressure equalized by opening and closing the vent and the bellows were stretched an additional half inch. Again system pressure was monitored for a two minute period after the initial delay of ten minutes. No significant leakage was observed in these two tests of the "Stoelting" "Pneumo" system.

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Leakage tests on the "Pneumo" system of the "Keeler" polygraph were performed in a similar manner, except for the elimination of the ten minute waiting period after pressurization because no shift was observed, and use of a bellows extension from 3 to 3 1/2 inches for the second test. The latter figure was used (instead of from 6 to 6 1/2 inches, as in the "Stoelting") because the bellows supplied with the "Keeler" are much thicker and stiffer. No significant leakage was observed in these two tests of the "Keeler" "Pneumo" system.

1.1.3 Static Calibrations of "Pneumo" System

The static calibrations of the "Pneumo" system of each polygraph were carried out in two sets of tests. In the first series, known pressures were applied to the input of the "Pneumo" system at the point where the chest bellows would normally be connected and the corresponding pen deflections were recorded.

In the second series of tests, the chest bellows connected to the "Pneumo" system, suspended vertically, were deflected linearly by known amounts, and the corresponding pen deflections were recorded.

1.1.3.1 Pressure Calibrations of "Pneumo" System

The experimental set-up for these calibrations is shown in Fig. 2. It consists of a "Pressure-Volume Variator" by Meriam Instrument Company, Cleveland, Ohio, (a bellows arrangement capable of generating static pressures above ambient), and a precision dial pressure gage, type FA-141, by Wallace and Tiernan, Belleville, New Jersey. The gage has a range of 0 to 40 inches of water (0 to about 79 mmHg) and an accuracy of 0.33% of full scale (± 0.13 inches of water or $\pm .24$ mmHg). Before the tests, the dial gage was exercised fifty times to stabilize characteristics. During the tests, pressures above and below the reference pressure were generated in increments of 1.87 mmHg (one inch of water). In each test, with the pen initially centered at the reference pressure, increments of pressure were applied in increasing and then decreasing directions, finally returning to the reference pressure. The applied pressure produced peak pen deflections of about ± 1 inch, within the maximum pen range of about $\pm 1 \frac{1}{4}$ inch. The tests were run at zero gage pressure and at 37.3 mmHg (20 inches of water), ± 1 for each of these with "light" and "heavy" pen condition. Two tests were made at each of these conditions. Values of deflection sensitivity, in terms of inches of deflection per mmHg were computed from deflections obtained for pressure steps of ± 7.46 mmHg (± 4 inches of water) with respect to the reference pressure.

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except in one case for the "Keeler" polygraph. In that case the pen deflection sensitivity was so large that pressure steps of ± 1.865 mmHg were used. Fig. 3 and 4 are graphs of the static pressure calibrations of the "Pneumo" systems (exclusive of bellows) of the "Stoelting" and "Keeler" polygraphs, respectively. The plotted calibrations are those for zero gage pressure, and the "light" pen; these being the conditions most likely to prevail during actual use of the polygraphs. The graphs indicate that linearity and hysteresis for both "Pneumo" systems are within about $\pm 2\%$ of the full range deflection. Averaged values from the data are given in Table 1.

The variations in deflection sensitivity with system reference pressure were further explored experimentally. Using the experimental static calibration set-up described previously, a system reference pressure of -37.3 mmHg was generated by means of the "Pressure-Volume Variator", the pen was positioned at the center of the chart by means of the zero adjustment control, and then the system pressure was increased 7.5 mmHg (to -29.8 mmHg). The resultant pen movement was recorded. At this pressure level, the pen was re-zeroed to the previous position and the pressure was raised by another 7.5 mm increment (to -22.4 mmHg) and the pen deflection was noted. This procedure continued in 7.5 mmHg pressure increments (for the "Stoelting"; the greater sensitivity of the "Keeler" required 3.75 mm increments). The final system reference pressure used was +29.8 mmHg. Tests were performed on the "Pneumo" channels of both polygraphs. The results are shown plotted in Fig. 5 and 6. The effect of pen pressure on deflection sensitivity is relatively small (less than 4%). The deflection sensitivities of both systems change with reference pressure, but in opposite directions. Thus for the "Stoelting" (Fig. 5), the deflection sensitivity at -29.8 mmHg is 117% of the zero reference pressure value, at +29.8 mmHg it is 82% of the zero reference pressure value. Corresponding values for the "Keeler" "Pneumo" system are 65% at -29.8 mmHg, and 205% at +29.8 mmHg. An additional test on the range of the zero adjustment control was made to determine the pressure necessary to center the "Pneumo" channel pen with this control in its two extreme positions. The data are compiled in Table 1.

1.1.3.2 Bellows Calibration of "Pneumo" Systems

The bellows calibration fixture shown in Fig. 2 is designed to suspend the bellows vertically and to permit extending it linearly by known amounts. With the freely suspended condition of the bellows constituting the zero position for the tests, the bottom end of the bellows was pulled down a fixed amount, to the reference position, the "Pneumo" system was vented to the atmosphere and then the vent was closed. The pen was centered by means of the zero adjustment

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control and then the bellows were deflected in known increments above and below the reference position and corresponding pen deflections were recorded. Tests were run for three reference positions for the "Stoelting" and two for the "Keeler", (the Keeler's" heavy wall bellows become excessively stiff when extended the maximum amount used for the "Stoelting"), and at two pen pressures, and were done twice for each condition. Deflection sensitivities were computed from deflections of about $\pm 1/2$ to $\pm 3/4$ inches from the center of the pen range (considered its most linear portion). Data are listed in Table 1.

Two of the curves obtained are plotted in Figures 7 and 8 and show relatively small departures from linearity (less than $\pm 3\%$ of the full deflection).

Variations in deflection sensitivity as a function of bellows reference position were explored in more detail. With the reference position changed in half-inch increments, after venting and closing of vent, the bellows were pulled down an additional 0.3 inch increment and the resultant pen deflection recorded. As may be seen from Fig. 9 and 10, the deflection sensitivity for both polygraphs decreases with increasing bellows extension. For the "Stoelting" (Fig. 9) the deflection sensitivity at a bellows extension of 4 1/2 inches is 83% of that at the one inch bellows extension reference. For the "Keeler" (Fig. 10) the corresponding factor is 49%. It should be noted that the "Stoelting" bellows could be stretched 7 inches without changing its cross sectional shape, the "Keeler" bellows only 4 1/2 inches.

Despite the differences in the design of the two chest bellows tested, the overall static deflection sensitivities of the two "Pneumo" systems in terms of pen deflection versus bellows extension are fairly similar.

Although the chest bellows are always used in conjunction with the "Pneumo" recording system, an additional test was performed to determine the actual pressures generated by linear deflection of the bellows. For these tests the bellows were connected through their proper connecting hose to the precision dial gages. Since bellows extensions generate pressures below ambient, the bellows were connected to the case of the dial gage in order to produce up scale readings. The volume of the pressure measuring system and connecting tubing determines the actual pressures generated. The case volume of the dial gage is 111 cubic inches (18'3 cubic centimeters). The volume of the tubing for the "Stoelting" is 0.9 cubic inch, for the "Keeler" 1.3 cubic inches. Data obtained are shown in Table 2.

1.1.4 Static Tests of "Cardio" Systems

A series of static tests were performed on the "Cardio" system

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of each polygraph to establish such characteristics as: quality of the built-in dial gage, deflection sensitivity at pen point, effect of zero adjustment control on deflection sensitivity, repeatability, and linearity.

1.1.4.1 Tests on Dial Gage of "Cardio" Systems

Static calibrations on the dial gages of the "Cardio" systems were performed by means of a primary pressure standard, Model 6-201, manufactured by Consolidated Electrodynamics. This device is a pneumatic dead-weight tester with accuracy stated by the manufacturer to be 0.015% of the pressure in the range of pressures used for those tests and is shown in Fig. 11.

The dial gages are approximately two inches in diameter and have a range of 300 mmHg. The scale is graduated in two-millimeter steps; graduations cease below 10 mm for the "Stoelting" and 20 mm for the "Keeler". In view of the cautions in the instruction manuals, the "Stoelting" was calibrated to only 150 mm and the "Keeler" to 140 mm, in steps of approximately 15 mmHg. Calibrations were performed with increasing and then decreasing pressures, with and without exercising the dial gage fifty times before the calibration.

The test results are shown in Tables 3. For the "Stoelting" dial gage the maximum error found was 3 mmHg or 1% of the full scale range. For the "Keeler" dial gage, the maximum error found was about 2.5 mmHg or a little less than 1% of the full scale range. Deviations from linearity, hysteresis, repeatability, resolution and the effect of exercise were all less than the maximum errors given above.

1.1.4.2 Static Pressure Calibrations of "Cardio" Systems

Static calibrations of the "Cardio" systems were made by means of the primary pressure standard Model 6-201 described above. The calibrations shown in Fig. 12 and 13 were performed at a system pressure of about 92 mm of mercury, a value in the center of the range of normal operation of the "Cardio" systems.

The selected value of system pressure was generated by the piston gage and the recording pen of the "Cardio" system was centered on the record by the centering control. Then the pressure was increased in fixed increments by adding small weights from the weight set supplied with the piston gage. When the maximum pressure was reached (corresponding to a deflection of about one inch from the center of the record), the pressure was decreased by removing the weights,

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this was continued until the pressure had dropped below the original system pressure by an amount sufficient to deflect the pen about one inch in the opposite direction from the center of the record. Then the pressure was increased again until the pen reached its original position in the center of the record.

The increments of pressure used for the calibrations plotted in Fig. 12 and 13 were 0.78 mmHg, the pressure change generated by adding or removing one of the standard 0.3 ounce weights.

The values of the deflection sensitivity for both "Cardio" systems repeated within 2%, and the "heavy" pen sensitivity ("Keeler") was found to be 95% of the "light" pen sensitivity. "Heavy" pen sensitivity for the "Stoelting" was not determined.

The graphs in Fig. 12 and 13 indicate that linearity and hysteresis for the "Cardio" system of the "Stoelting" are within $\pm 1\%$ of the full range deflection, for the "Keeler" within $\pm 5\%$ of the full range deflection. The deflection sensitivities were somewhat different also: 0.249 inches mmHg for the "Stoelting", and 0.323 inches mmHg for the "Keeler". A series of tests was made to investigate the effect of system pressure on the deflection sensitivities of the "Cardio" systems of the two polygraphs. Similar to the procedure used above, the pen deflection, produced by an incremental pressure change, was recorded at a number of system pressures; ranging from about 49 to 147 mmHg for the "Stoelting", and from 57 to 135 mmHg for the "Keeler". The results of the tests are presented in Fig. 14 and 15.

It can be seen that the deflection sensitivity of the "Cardio" system of the "Stoelting" does not vary by more than 23% from its value at 92 mmHg over the entire range of system pressures from 49 mm to 147 mm. On the other hand, the "Cardio" system of the "Keeler" (Fig. 15) shows a considerably greater variation in deflection sensitivity which decreases with increasing system pressure. Referred to the value at 93 mm, the deflection sensitivity at 57 mm is 172%, while at 135 mm it is 67%.

2. DYNAMIC TESTS ON POLYGRAPHS

2.1 General Considerations

The dynamic response of these systems may be affected by the factors that influence static performance, such as pen pressure and system pressure level, as well as by others such as deflection amplitude, use of "resonance control" ("Cardio" system), and length of rubber

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connecting hoses. These factors must be considered in the dynamic tests.

2.2 Dynamic Calibration Equipment

Fig. 16 shows a general view of the dynamic calibration equipment used for the evaluation of the "Pneumo" and "Cardio" systems of the polygraphs. A detailed schematic of the calibration system is shown in Fig. 17.

The heart of the system is a modified aquarium pump, "Marvel Airflow, Model C" made by the Magnus Manufacturing Corporation, Maywood, N.J. The pump was modified by sealing up the annular air intake slot at the outside end of the cylinder and by replacing the constant speed ac motor which came with the pump. The replacement dc motor is part of a system made by Electrocraft, Hopkins, Minn. This "E-600 motor speed control system" permits continuously adjustable speeds from 5 rpm to 3000 rpm.

The basic system uses the motor driven pump to generate sinusoidal volume variations in the pneumatic system comprising tubing, valves, gages and the polygraph. By adjusting the overall volume of the pneumatic system the pressure variations resulting from the pump-generated volume variations can be adjusted to the desired amplitudes. The adjustable hose clamp shown permits an additional, continuous, variation of the amplitude. The differential pressure transducer Model PT 14-2, Range ± 1 PSI (± 51.7 mmHg or ± 27.7 inches water) made by Dynisco, Cambridge, Mass. in conjunction with its power supply, Harrison Labs. Model 801 C, a dc amplifier, Sanborn 8875A, and an oscilloscope, Tektronix, Model 535 is used to measure the sinusoidal pressures applied to the polygraph. In addition, the output of the pressure transducer is recorded on an oscillograph "Visicorder" model 906B by Honeywell.

The limit of error of the static calibration of the differential pressure transducer is less than $\pm 2\%$ of the pressures within the range of interest. Based on the design of the transducer we believe that the lowest acoustic resonance of the transducer is sufficiently above the frequency range used for dynamic calibrations (-0.17 Hz to 11) that the frequency response of the transducer can be considered to be essentially flat over this range.

To permit operation at some fixed pressure levels above ambient, as required for some of the dynamic tests of the "Cardio" system, compressed air is used. Fig. 17 indicates the cylinder of compressed air, pressure regulator, and various valves for fine adjustment of the pressure.

Finally, the drawing shows the "Pressure Volume Variator" and the precision dial gage attachment to the other side of the differential pressure transducer. This arrangement performs two functions. It permits static calibration of the pressure transducer system (in-

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cluding the monitoring oscilloscope) by generating known increments of static pressure, that can be read on the precision dial gage. Sinusoidal pressure variations observed by means of the oscilloscope can then be related to known static pressures provided the dynamic characteristics of the pressure transducer system are known.

In addition, it permits both sides of the transducer to be pressurized to the desired fixed operating pressure level to avoid overloading of the transducer during operation at base pressures above ambient for "Cardio" system tests.

A test was run on the dynamic calibration system in which the transducer output was monitored while the system was subjected to sinusoidal pressure variations generated by the constant displacement pump. The transducer output shows an almost linear increase with frequency, reaching a value about 11% above static at 5 Hz and 31% at 9.3 Hz. For the dynamic tests on the polygraph, the transducer output was taken to represent the pressure applied to the input of the polygraph. During actual use of the polygraph, the chart drive speed of 0.1 inches per second of both polygraphs makes it very difficult to resolve any frequencies above 2 Hz, consequently the dynamic characteristics of the monitoring system are considered quite adequate for these tests.

2.2.1 Dynamic Tests on "Pneumo" Systems

Dynamic tests on the "Pneumo" systems of the two polygraphs were performed over the frequency range 0.17 Hz to 1.2 Hz with "light" and "heavy" pens, at zero system pressure and at system pressure of 37.3 mmHg. Tests were made by applying the pressure variation to the "Pneumo" input fitting of the polygraph and also with the rubber hose normally used to connect the bellows inserted between the "Pneumo" input and the dynamic calibration equipment.

Initial (low-frequency) pen deflection was set at 0.5 to 0.75 in (approximately half scale) to accommodate the rapid rise in response of the "Pneumo" system with frequency. Some additional tests were run with 1.20-in. initial deflection.

Although the resolution of recorded frequencies appears limited to those below 2 Hz, the low degree of damping in the "Pneumo" systems which causes the large rise in response at resonance, may cause excessive magnification of harmonics of low frequencies. To explore this, dynamic calibrations were carried on up to 11 Hz.

The results of these dynamic calibrations at frequencies from 1.7 Hz to 11.2 Hz on the "Pneumo" system of the "Stoelting" polygraph are shown in Fig. 18. It will be noted that calibration points between 0.17 Hz and 1.7 Hz (low range achieved by gear reduction between motor and pump) were not plotted. They substantially follow the shape of the plotted curves down to the static calibration and add little to the knowledge of system characteristics.

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As may be seen from the curves plotted in Fig. 18, the "Pneumo" system of the "Stoelting" appears to have a resonance at about 8.3 Hz at zero system pressure. Since the pen deflection is limited by the stops over a band of frequencies near resonance even with small initial deflection, the exact location of the resonance was not determined. As expected, insertion of the long connecting tube, lowered the system resonance slightly. Operation at a system pressure 37.3 mmHg (20 inches of water) appears to raise the resonance to about 8.8 Hz, while lowering the deflection sensitivity of the system. (See Fig. 5). Tests with "heavy" pen and full scale pen movement did not show any significant differences.

The dynamic characteristics of the "Pneumo" system of the "Keeler" polygraph are shown in Fig. 19. The resonant frequency for "standard" conditions (zero reference pressure, "light" pen, no connecting tube) appears to be about 8 Hz (close to the value for the "Stoelting"), however at a system pressure of 37.3 mmHg, the system response is quite different, with resonance lowered to about 5.3 Hz, much lower damping and much higher deflection sensitivity (See Fig. 6). Effects of "heavy" pen and long connecting tube at zero reference pressure on resonant frequency are not significant.

2.2.2 Dynamic Tests on "Cardio" Systems

Dynamic tests on the "Cardio" systems of the two polygraphs were performed over frequencies from about 0.17 Hz to 11.2 Hz with "light" and "heavy" pens, at system pressures of about 60.90, and 120 mmHg. Additional tests were made with the long rubber connecting tube between the "Cardio" input and the dynamic calibration equipment. Further tests were made to determine the influence of the resonance control. While most tests were performed with an initial low frequency pen deflection of one half to three quarters of an inch (about "half scale"), additional tests were made using an initial low frequency deflection of about one to one and one quarter inches (nearly "full scale").

As in the "Pneumo" system, the low degree of damping in the "Cardio" system causes a large rise in response at resonance. Dynamic calibration data points at frequencies between 0.17 Hz and 1.7 Hz were not plotted in Fig. 20, and 21 which show the dynamic characteristics of the "Cardio" systems of the two polygraphs. These very low frequencies points follow substantially the shape of the plotted curves down to the static calibrations.

As may be seen from the graphs in Fig. 20, the "Cardio" system of the "Stoelting" appears to have a resonance at about 4 Hz which is not significantly changed by operation at the three levels of system pressure: 59.89 and 121 millimeters of mercury, or with the "heavy" pen (Fig. 20, right graph). Sensitivities at these three pressure levels differ, corresponding to the deflection sensitivities determined statically (See Fig.

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14). Operation with the long tube appeared to lower the value of resonance to about 3.7 Hz, as did "full scale" deflection. The "resonance" control has a considerable effect as may be seen from the graph on the right hand side of Fig. 20. From its fully "out" position, the resonance control can be turned "in" (clockwise) for about fifteen turns without affecting deflection amplitude at 1.7 Hz. This was chosen as a convenient initial frequency with a dynamic deflection sensitivity very close to that of the static calibration. Upon further clockwise turning of the resonance control, somewhat less than a quarter of a turn, the deflection sensitivity drops to the value shown on the graph. The frequency response obtained with the resonance control in this position is plotted in Fig. 20. The response appears well damped, with a peak response at about 3.3 Hz. Further turning of the resonance control for less than an additional quarter turn shuts the system off completely. Thus within less than a half turn of this control, the response of the "Cardio" system can change from a sensitive "lightly" damped system with a high resonant rise at about 3.7 Hz to a totally non-responding system. This high sensitivity of the "resonance" control could lead to serious errors in the operation of the system.

The dynamic characteristics of the "Cardio" system of the "Keeler" polygraph are shown in Fig. 21. As may be seen from the characteristics plotted on the left side of this graph, the resonance of the "Cardio" system of this polygraph is a function of the system pressure. At a system pressure of 57 mm of Hg, the resonance appears to be at 3.3 Hz; at 89 mmHg, the resonance has shifted to about 4.3 Hz; at 120 mmHg, the peak response occurs at about 5 Hz. In the latter case the damping appears to be larger also. The dynamic deflection sensitivities are also different at these three system pressures, but correspond (at very low frequencies) to the values obtained from the static calibrations.

Operation with the "heavy" pen shows a lowered deflection sensitivity and a slightly lower resonance than that obtained with the "light" pen (4.3 Hz) at the same system pressure. The use of the long tube lowers the deflection sensitivity (about 25% at 2 Hz) and resonance from about 4.5 Hz to about 3.3 Hz. The setting of the resonance control, as observed previously with the "Stoelting" has a considerable effect on the dynamic characteristics of the "Cardio" system of the "Keeler" also.

Apart from the effects of the resonance control, the dynamic characteristics of the "Cardio" system of the "Stoelting" while indicating a frequency response with undesirably low damping, are relatively unaffected by variations in operating parameters such as system pressure, pen pressure deflection amplitude and long connecting tubes. The dynamic characteristics of the

ATTACHMENT 1

"Cardio" system of the "Keeler", however are greatly affected by variations in operating parameters, in addition to showing undesirably low damping. It would appear more difficult to obtain meaningful data by the use of this system.

ATTACHMENT 1

TABLE 1

Performance Characteristics of "Pneumo" Systems of Polygraphs

Characteristic	"Stoelting"	"Keeeler"	Report Section
	"Light Pen"	"Heavy Pen"	
Pressure calibration deflection sensitivity			
Inches per millig at zero gage pressure	0.0847	0.0846	0.104
at 20 in. of water (37.3 millig)	0.0649	-	0.270
"Zero adjustment control" range pressure, millig	-38.2 +36.8	-	-90.2 +85.6
Fellows calibration deflection sensitivity			
Inches per inch bellows deflection			
Reference Positions	3.58	-	1.1.3.2
1 3/16 inches	-	-	
1 inch	-	-	3.67
2 21/32 inches	2.82	2.80	-
3 inches	-	-	2.72
5 27/32 inches	2.34	2.31	-

See i.1.1

i.1.3.1

i.1.3.1

-

-

-

-

ATTACHMENT 1

TABLE 2

Bellows Calibration of Polygraphs

Deflection from freely suspended position inches	"Stoebling" Pressure Generated mmHg	"Keeeler" Pressure Generated mmHg
0	0	0
0.5	0.60	3.0
1.0	1.3	5.8
1.5	2.1	8.6
2.0	2.6	10.8
2.5	3.4	13.4
3.0	4.1	15.5
3.5	4.8	17.5
4.0	5.6	19.4
4.5	6.3	21.2
5.0	7.1	----
5.5	7.6	----

6 feet connecting tubing
 1/8 inch I.D.
 volume 0.9 cubic inches
 Dial gage case volume 111 cubic inches

4 feet connecting tubing
 3/16 inch I.D.
 volume 1.3 cubic inches

ATTACHMENT 1

TABLE 3

Calibrations of Dial Gages of Polygraphs

"Stopitng"

Applied Pressure PSI	mmHg	Dial Gage Reading		Dial Gage Reading		Dial Gage Reading	
		Gage Exercised	No Gage Exercised	Gage Exercised	No Gage Exercised	Gage Exercised	No Gage Exercised
0.30	15.51	14.4	15.0	14.4	15.4	14.8	14.8
0.60	31.03	29.6	29.8	29.6	30.0	29.8	29.8
0.90	46.54	44.4	44.8	44.2	45.2	44.4	44.4
1.20	62.06	60.0	59.8	60.0	60.2	60.0	59.8
1.50	77.57	75.2	75.6	75.6	75.0	75.2	75.6
1.80	93.09	90.4	90.4	90.4	90.8	90.4	90.2
2.10	108.6	105.6	105.8	106.2	106.4	106.0	105.8
2.40	124.1	121.8	121.2	121.6	122.0	121.8	121.4
2.70	139.6	137.8	137.6	137.6	137.6	137.6	137.0
3.00	155.2		153.0		153.4		153.2

"Keeler"

Applied Pressure PSI	mmHg	Dial Gage Reading		Dial Gage Reading		Dial Gage Reading	
		No Gage Exercised	Gage Exercised	No Gage Exercised	Gage Exercised	No Gage Exercised	Gage Exercised
0.30	15.51	off scale		off scale		off scale	
0.60	31.03	32.0	33.2	32.4	32.8	32.4	32.8
0.90	46.54	47.6	48.4	48.0	48.4	47.6	48.4
1.20	62.06	63.2	64.4	63.6	64.0	63.6	64.4
1.50	77.57	78.8	80.0	79.2	79.6	78.8	79.6
1.80	93.09	94.0	95.2	94.4	94.8	94.4	94.8
2.10	108.6	109.6	110.4	109.6	110.0	109.6	110.4
2.40	124.1	124.8	125.6	125.2	125.2	125.2	125.2
2.70	139.6		140.4		140.4		140.8

FIG. 1A TOP VIEW OF "DECEPTOGRAPH" MADE BY C. H. STORLTING CO.

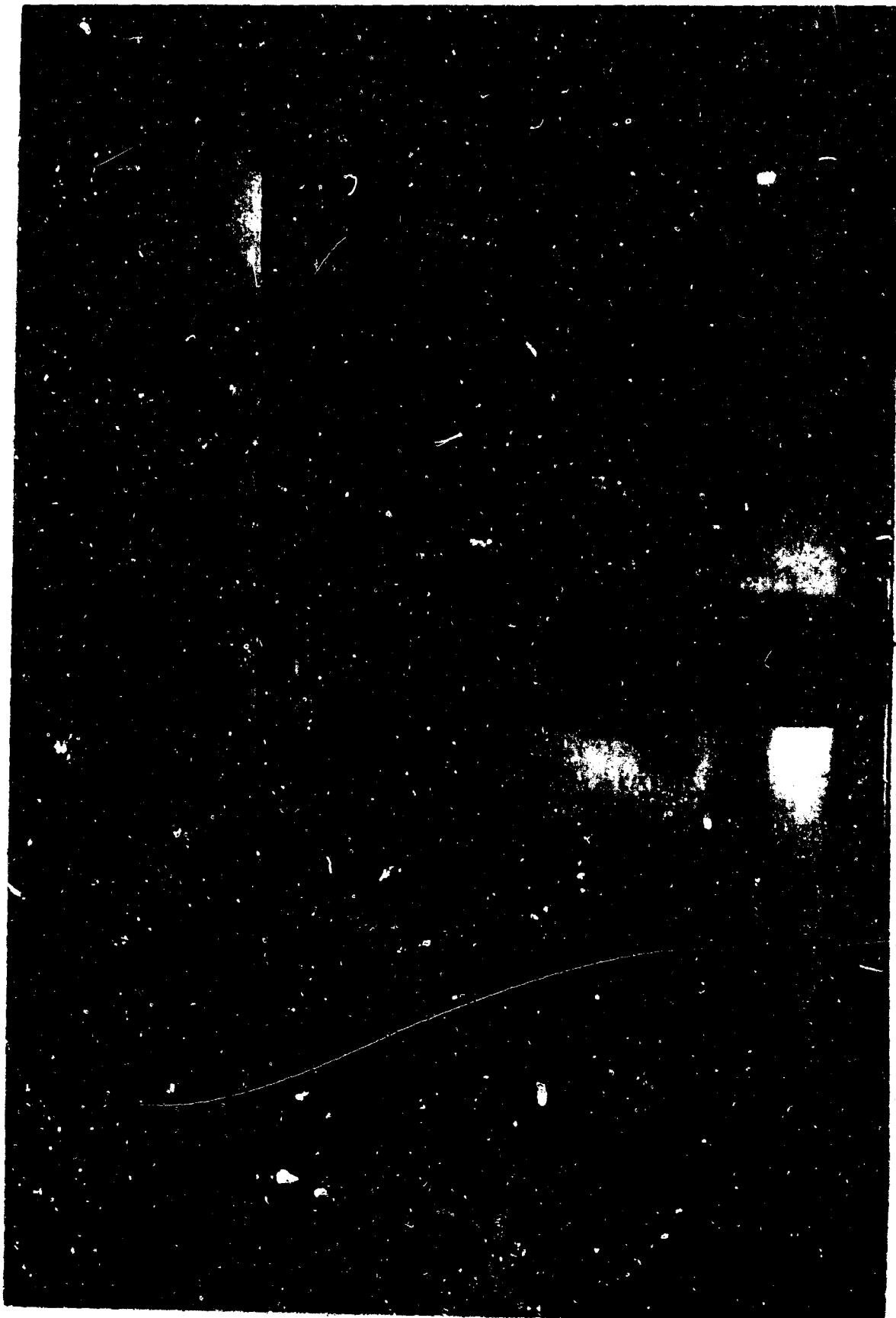
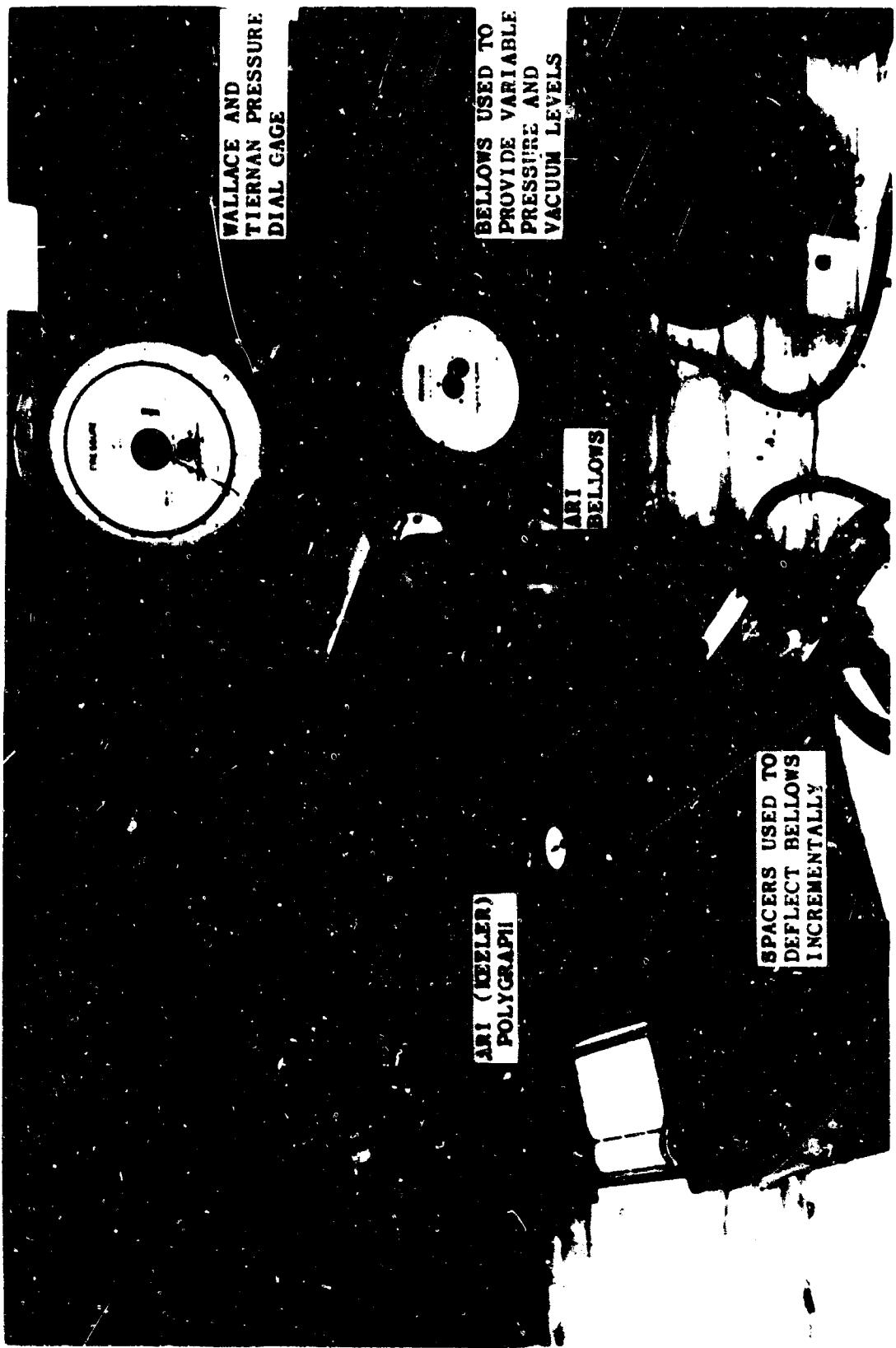


FIG. 1B TOP VIEW OF "KEEFER" POLYGRAPH MADE BY ASSOCIATED RESEARCH, INC.





F.G. 2 VIEW OF STATIC CALIBRATION SET-UP FOR PNEUMO SYSTEMS AND CHEST BELLOWS

FIG. 3 STATIC PRESSURE CALIBRATION OF "PNEUMO" SYSTEM OF "STOEHLING"
POLYGRAPH (EXCLUSIVE OF BELLOWS) AT REFERENCE PRESSURE OF 0
GAGE PRESSURE AND WITH "LIGHT" PEN.

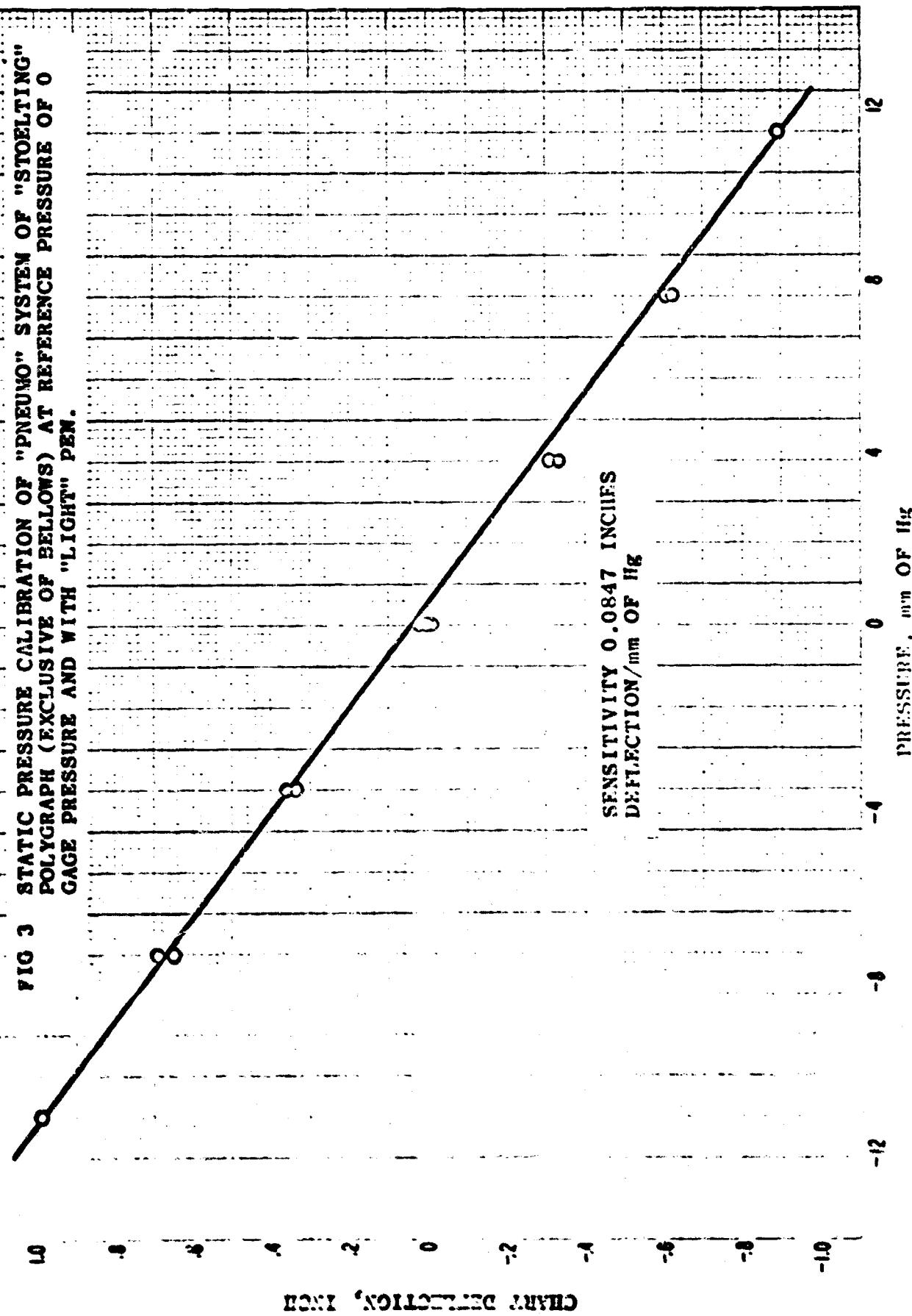
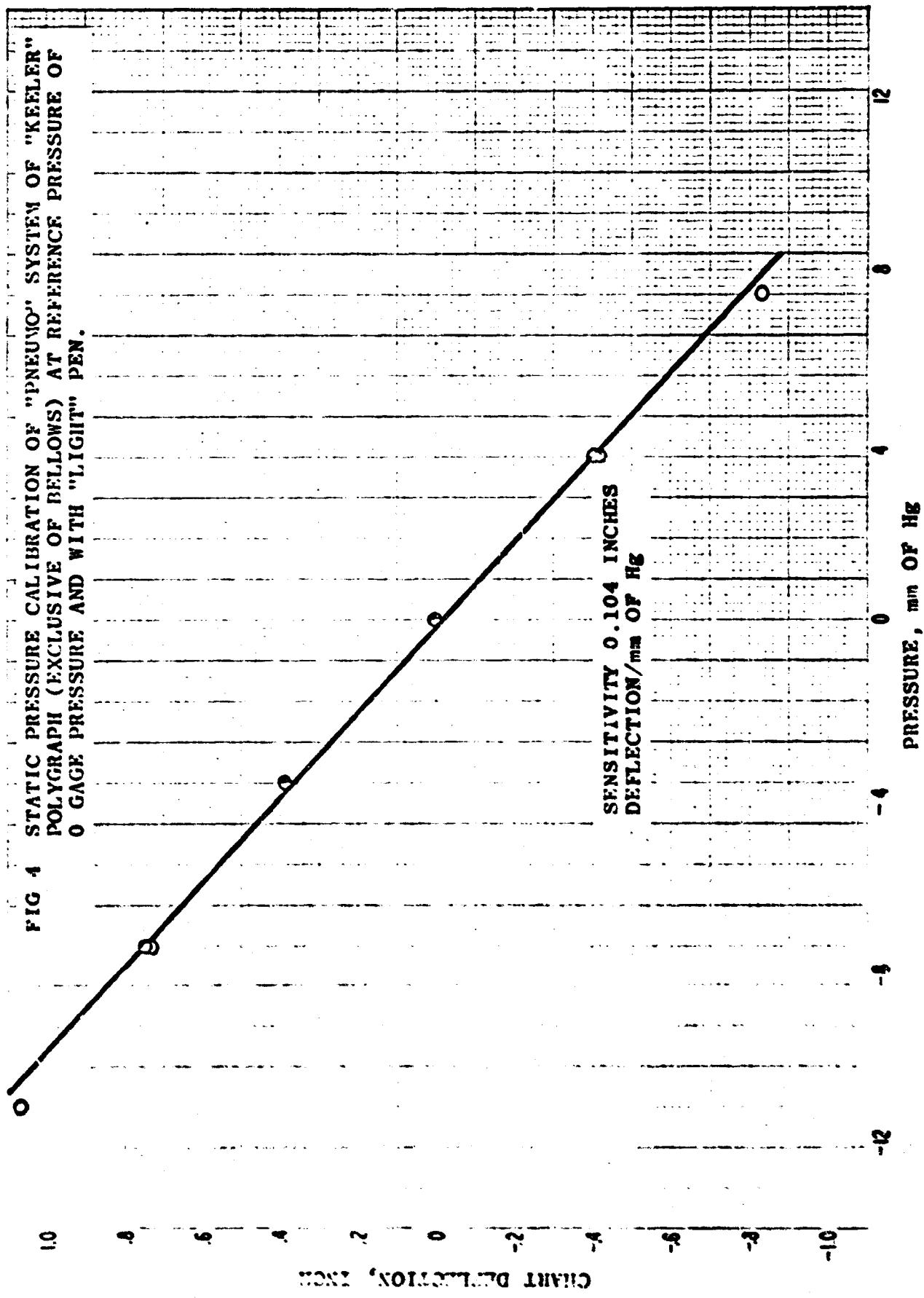


FIG. 4 STATIC PRESSURE CALIBRATION OF "PNEUMO" SYSTEM OF "KEELEER"
POLYGRAPH (EXCLUSIVE OF BELLOWS) AT REFERENCE PRESSURE OF
0 GAGE PRESSURE AND WITH "LIGHT" PEN.



**FIG. 5 VARIATION OF DEFLECTION SENSITIVITY OF "PNEUMO" SYSTEM
(EXCLUSIVE OF BELLOWS) OF "STOEHLING" POLYGRAPH WITH
"LIGHT" PEN AS A FUNCTION OF REFERENCE PRESSURE.**

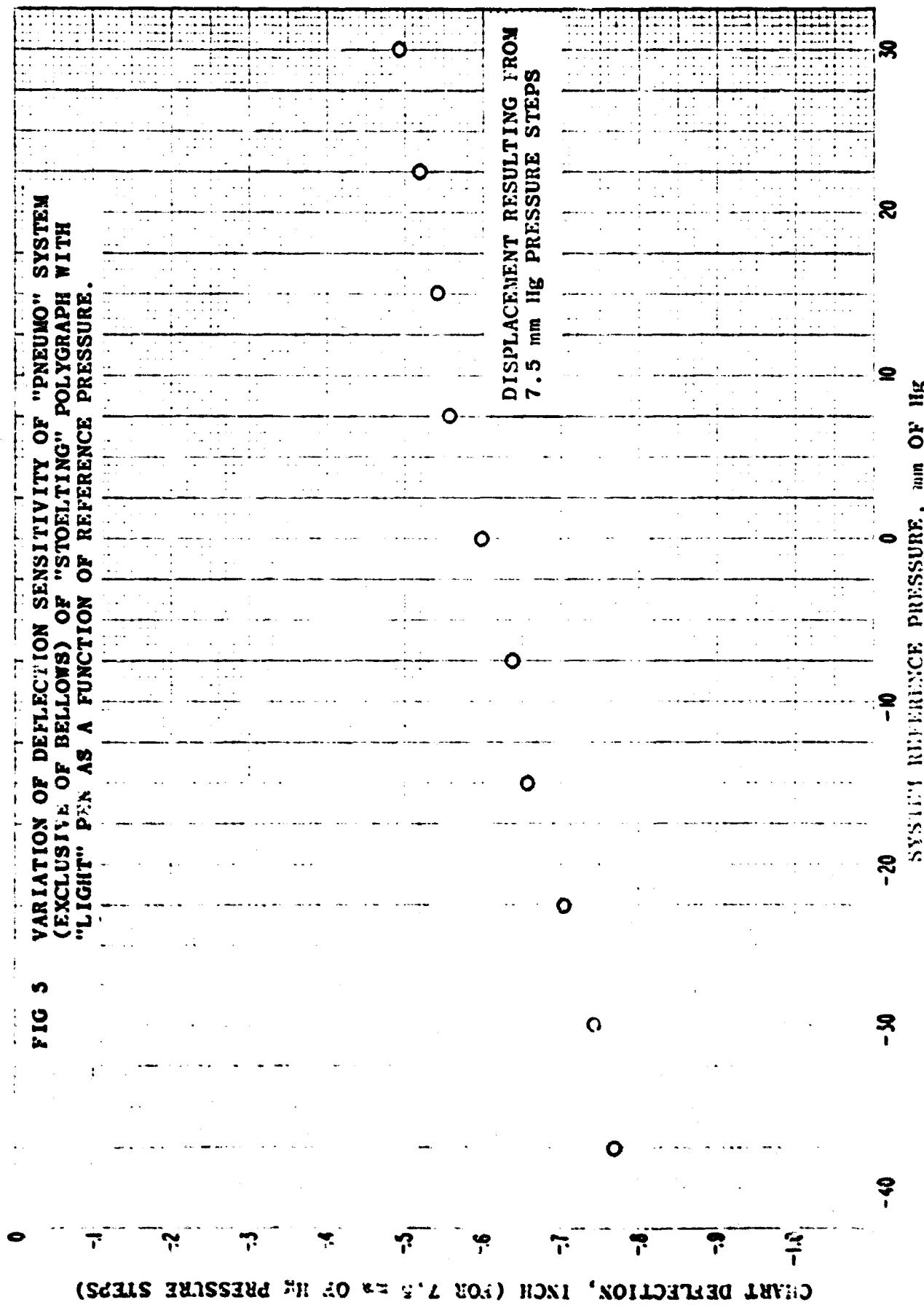


FIG. 6 VARIATION OF DEFLECTION SENSITIVITY OF "PNEUMO" SYSTEM
(EXCLUSIVE OF BELLOWS) OF "KEELER" POLYGRAPH WITH
"LIGHT" PEN AS A FUNCTION OF REFERENCE PRESSURE.

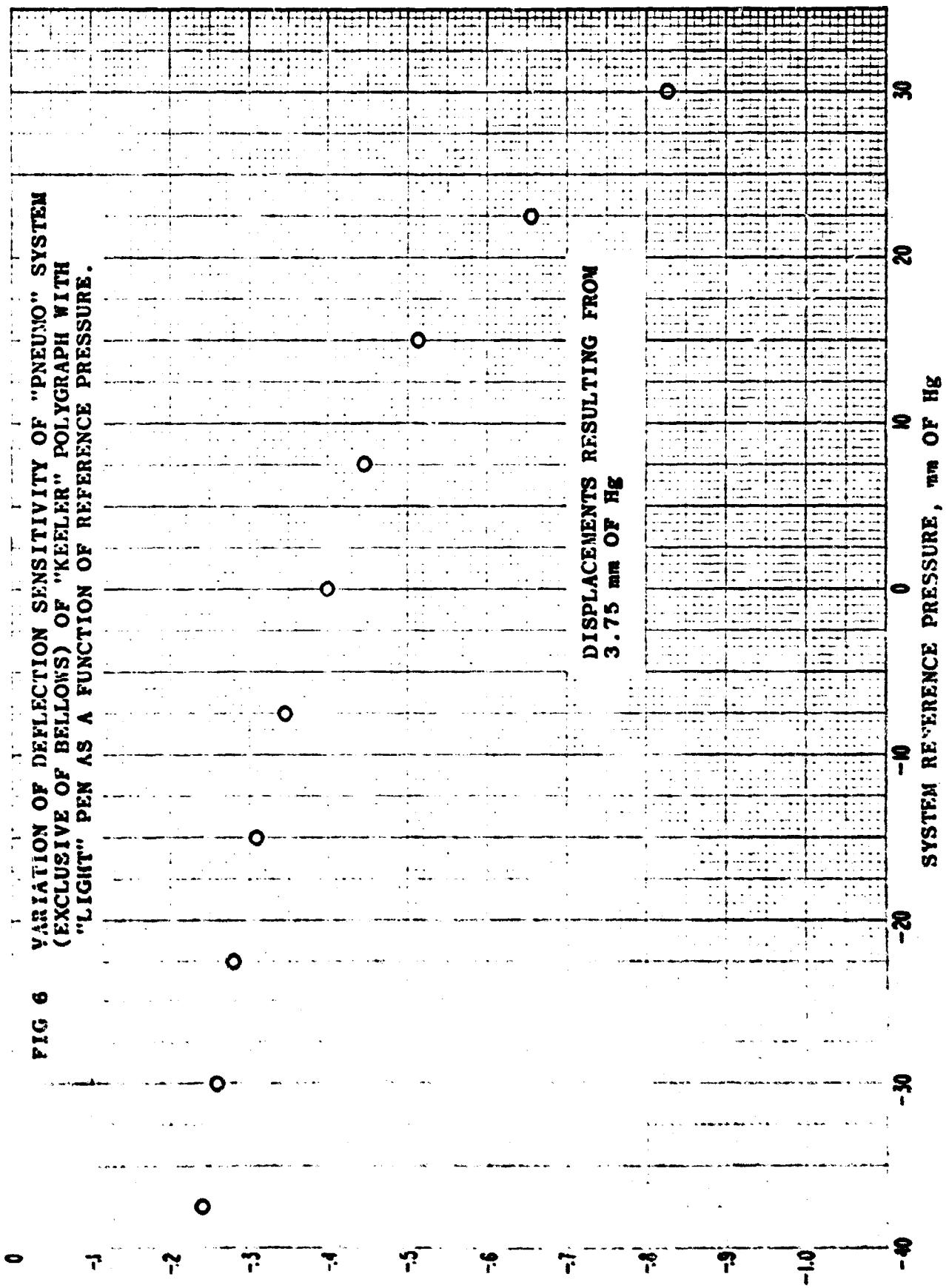


CHART DEFLECTION, INCH (FOR 3.75 MM OF HG PRESSURE STEPS)

FIG. 7 BELLows DEFLECTION CHARACTERISTICS FOR "PNEUMO" SYSTEM
OF "STOEFLING" POLYGRAPH WITH "LIGHT" PEN FROM REFERENCE
POSITION OF 2 23/32 INCH.

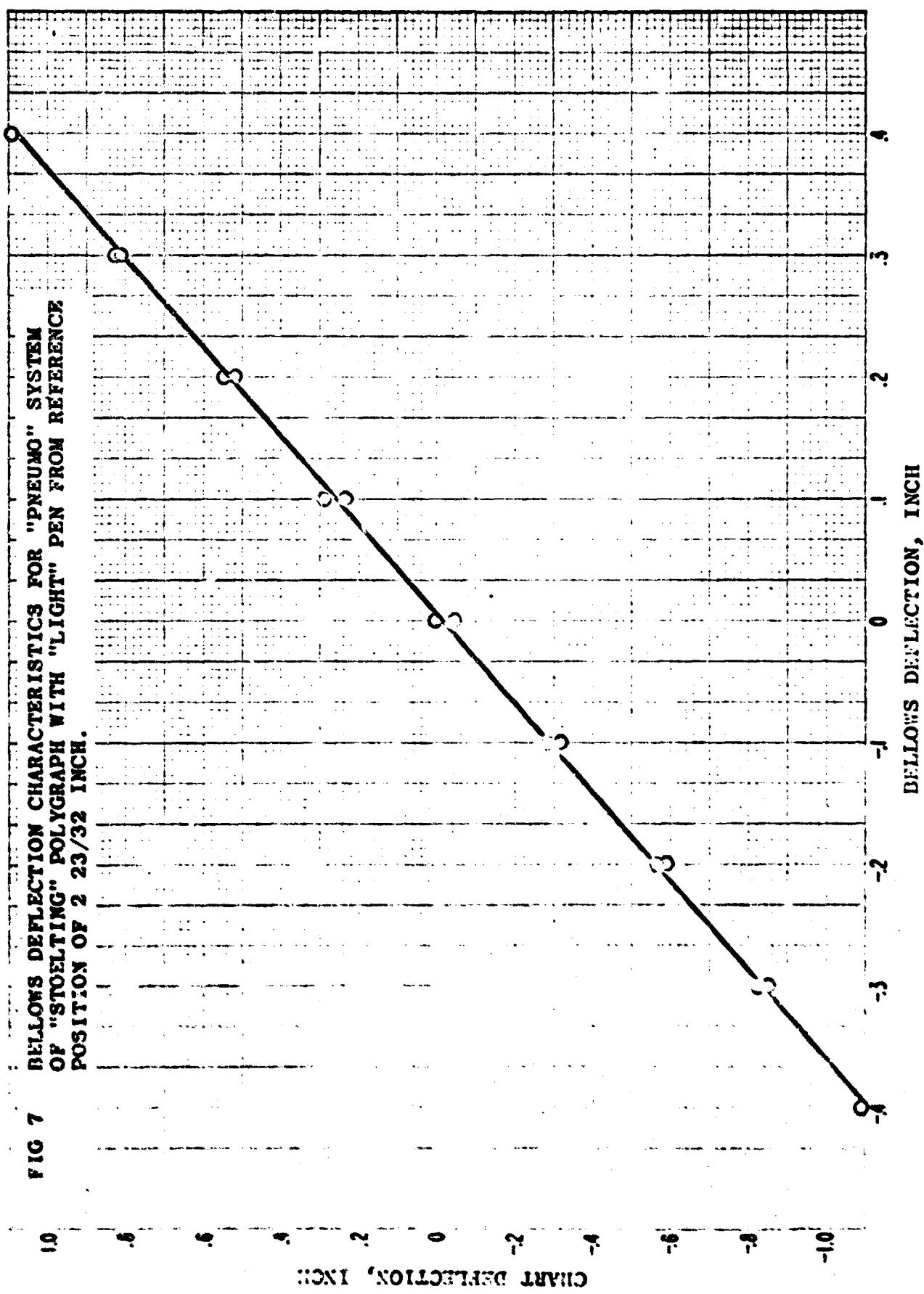
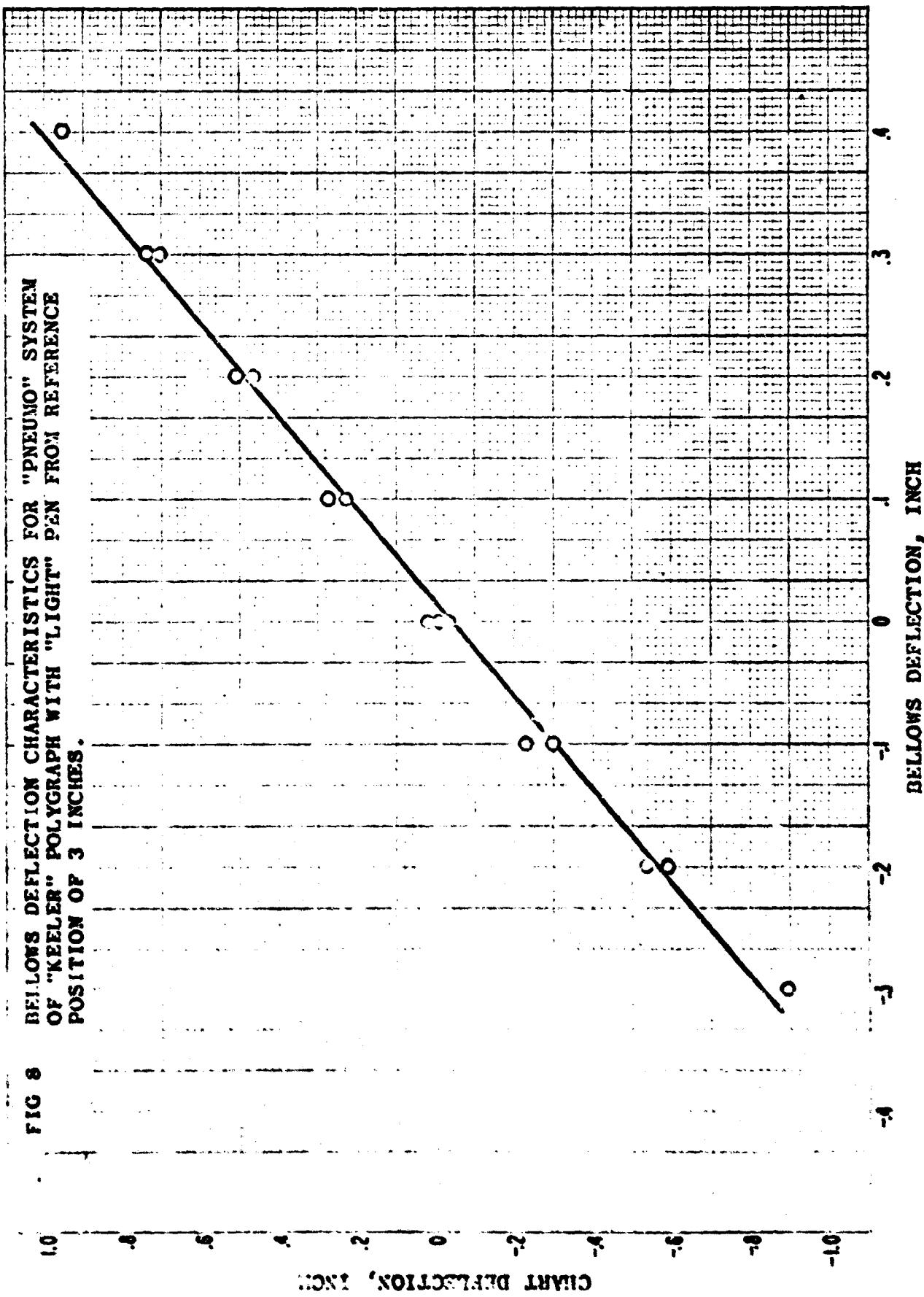
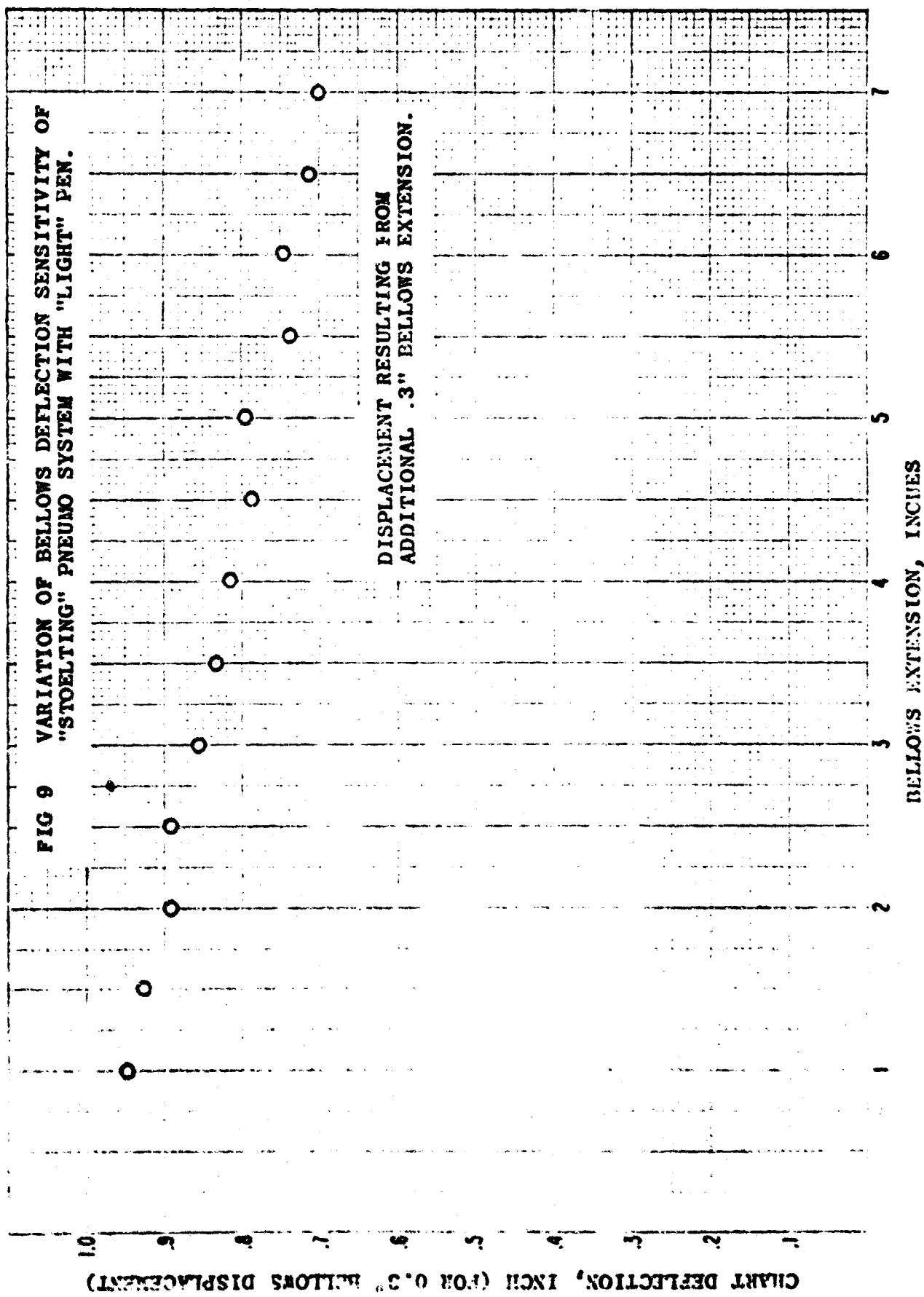


FIG 8 BEVELS DEFLECTION CHARACTERISTICS FOR "PNEUMO" SYSTEM
OF "KEELER" POLYGRAPH WITH "LIGHT" PEN FROM REFERENCE
POSITION OF 3 INCHES.



**FIG 9 VARIATION OF BELLows DEFLECTION SENSITIVITY OF
"STOELTING" PNEUMO SYSTEM WITH "LIGHT" PEN.**



**FIG 10 VARIATION OF BELLows DEFLECTION SENSITIVITY OF
"KEELER" PNEUMO SYSTEM WITH "LIGHT" PEN.**

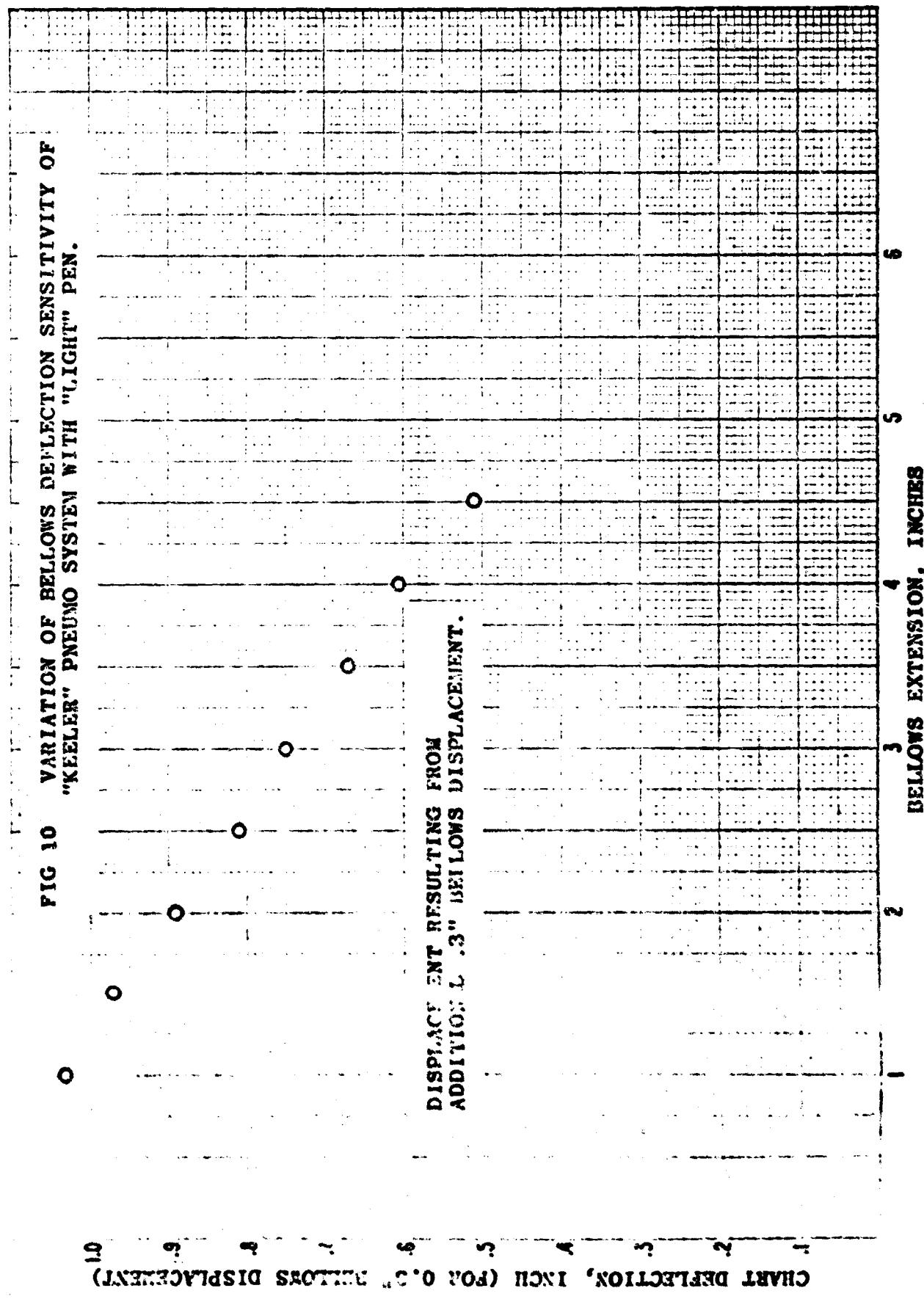




FIG. 11 AIR PISTON GAGE USED FOR STATIC CALIBRATION OF CARDIO SYSTEMS

FIG 12 STATIC PRESSURE CALIBRATION OF "CARDIO" SYSTEM OF
"STOEHLING" POLYGRAPH WITH "LIGHT" PEN AT SYSTEM
PRESSURE OF 92 mm OF MERCURY.

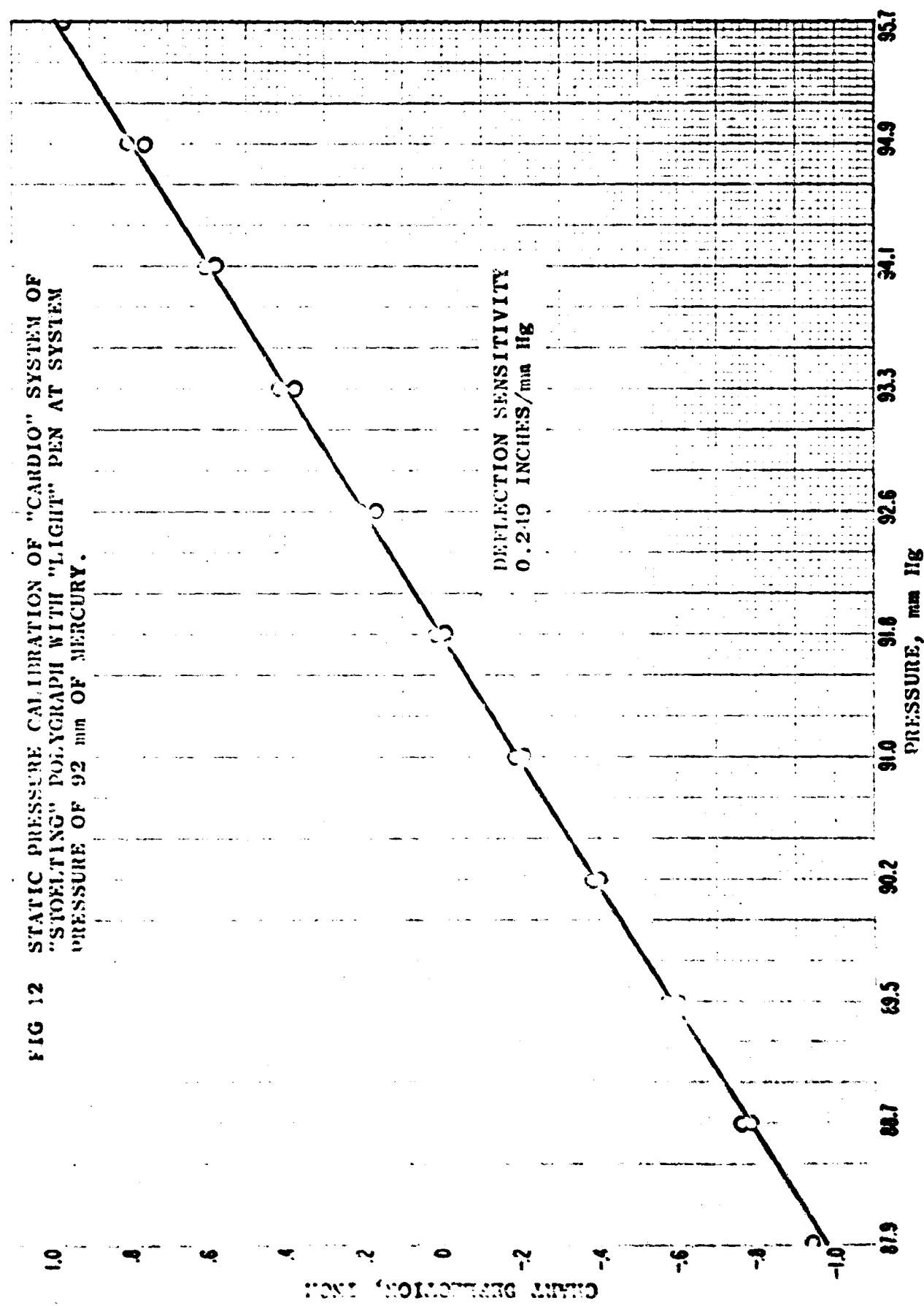


FIG 13 STATIC PRESSURE CALIBRATION OF "CARDIO" SYSTEM OF
"KEELEER" POLYGRAPH WITH "LIGHT" PEN AT SYSTEM
PRESSURE OF 91 mm MERCURY.

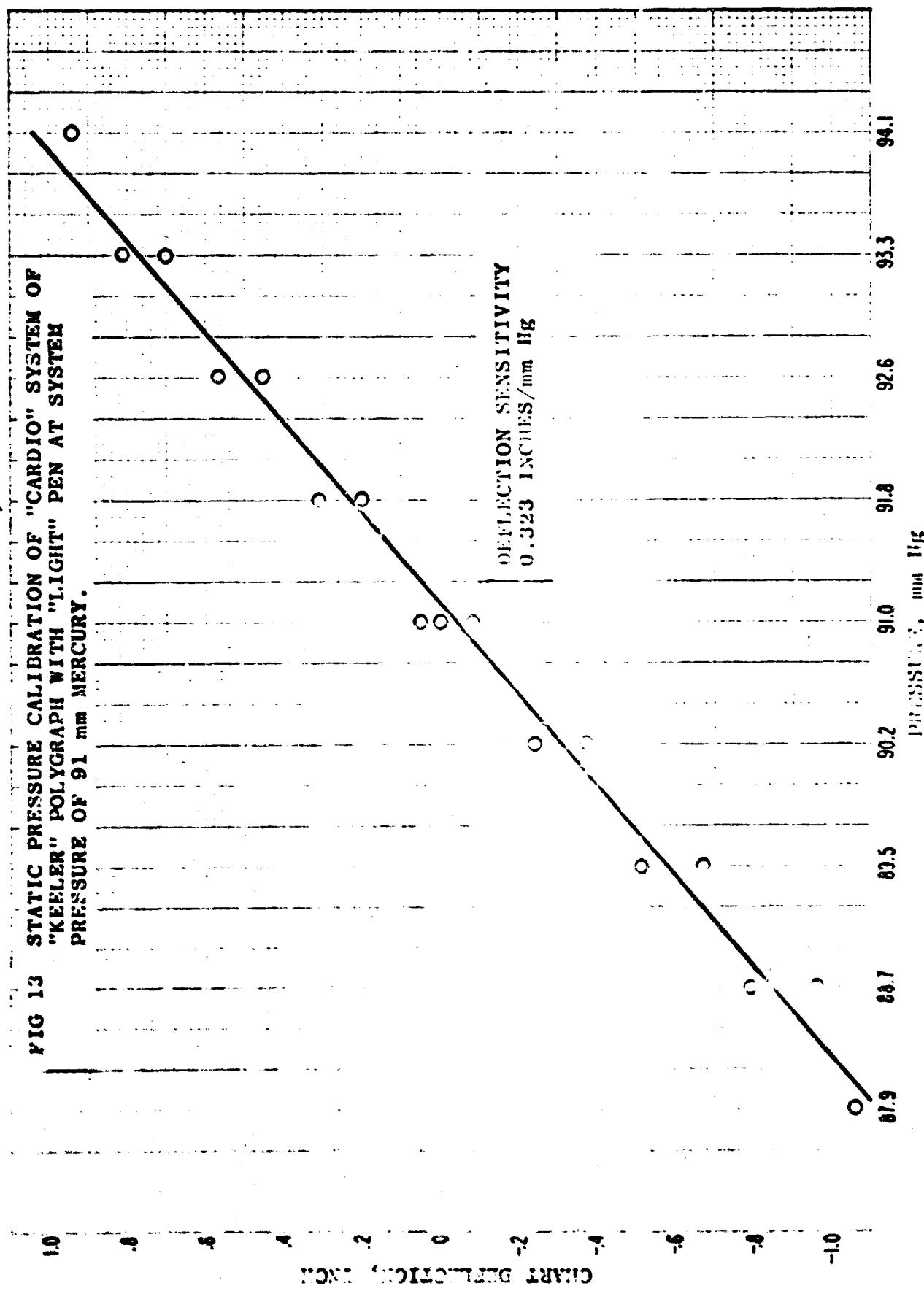


FIG. 14 DEFLECTION SENSITIVITY OF "CARDIO" SYSTEM OF "STOELTING"
PEN WITH "RIGHT" PEN AS A FUNCTION OF SYSTEM PRESSURE.

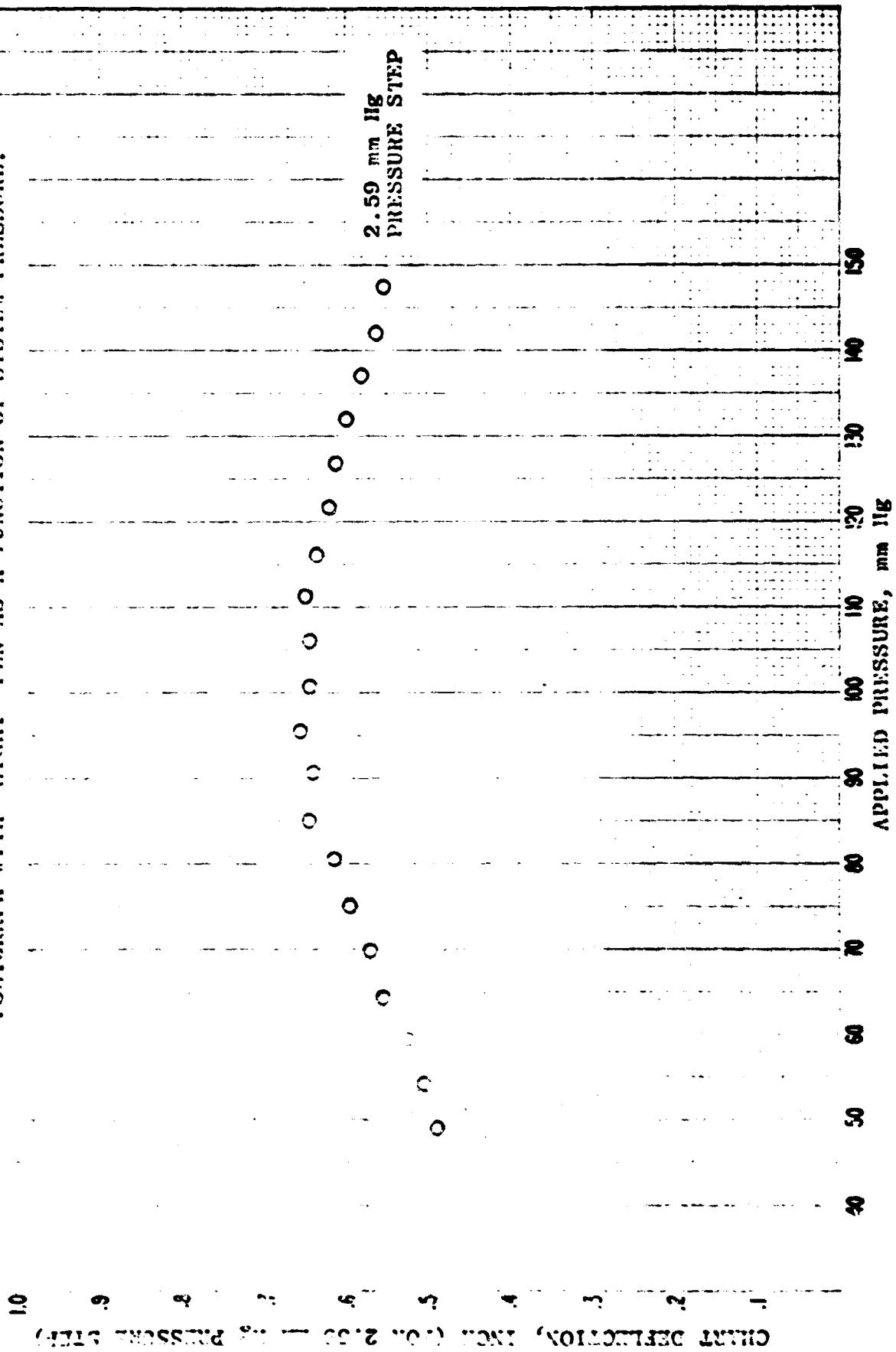


FIG 15 DEFLECTION SENSITIVITY OF "CARDIO" SYSTEM OF "KEELER" POLYGRAPH WITH "LIGHT" PEN AS A FUNCTION OF SYSTEM PRESSURE.

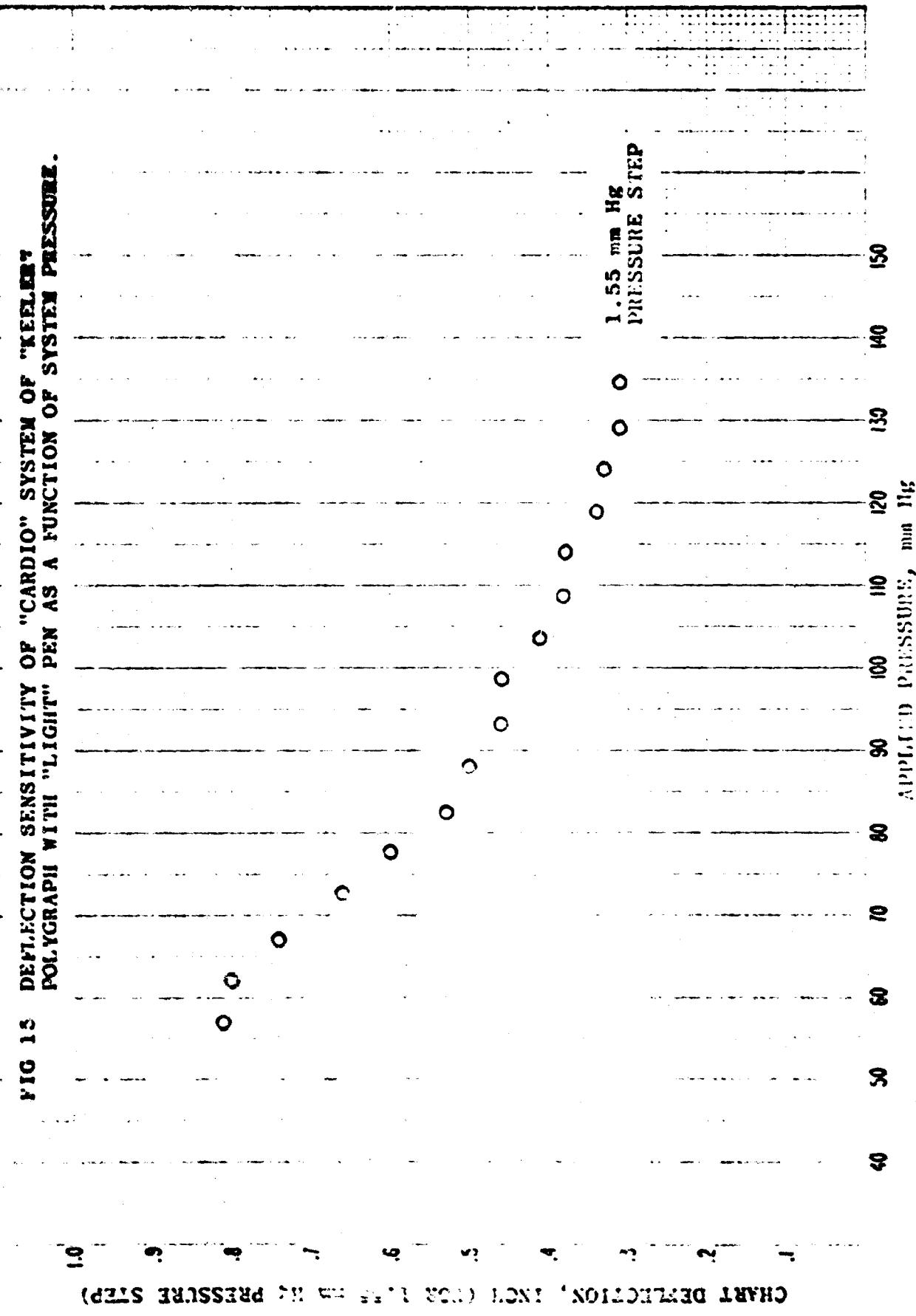




FIG. 16 VIEW OF DYNAMIC CALIBRATION EQUIPMENT FOR "PISTO" AND "CARBIO" SYSTEMS

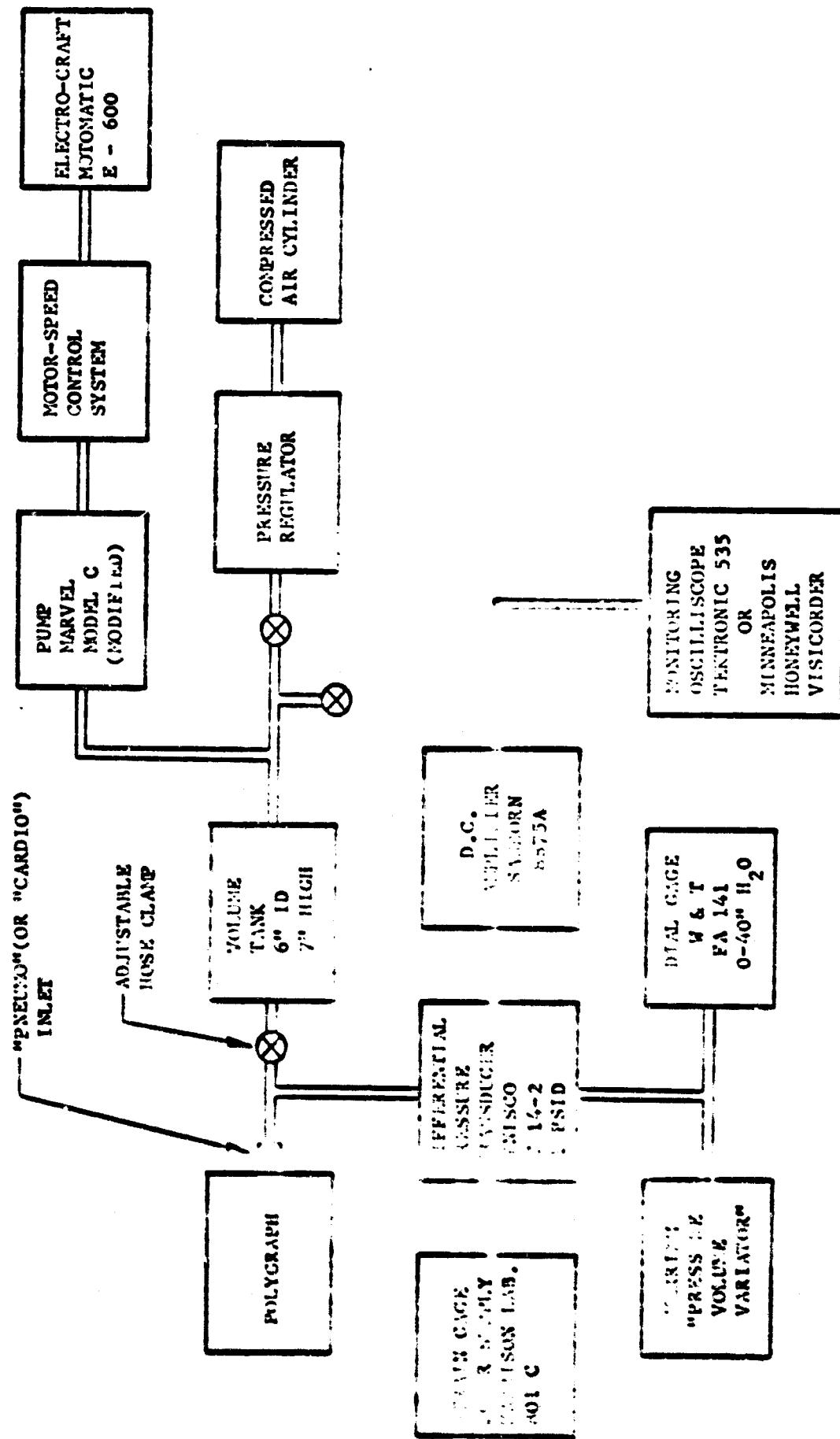
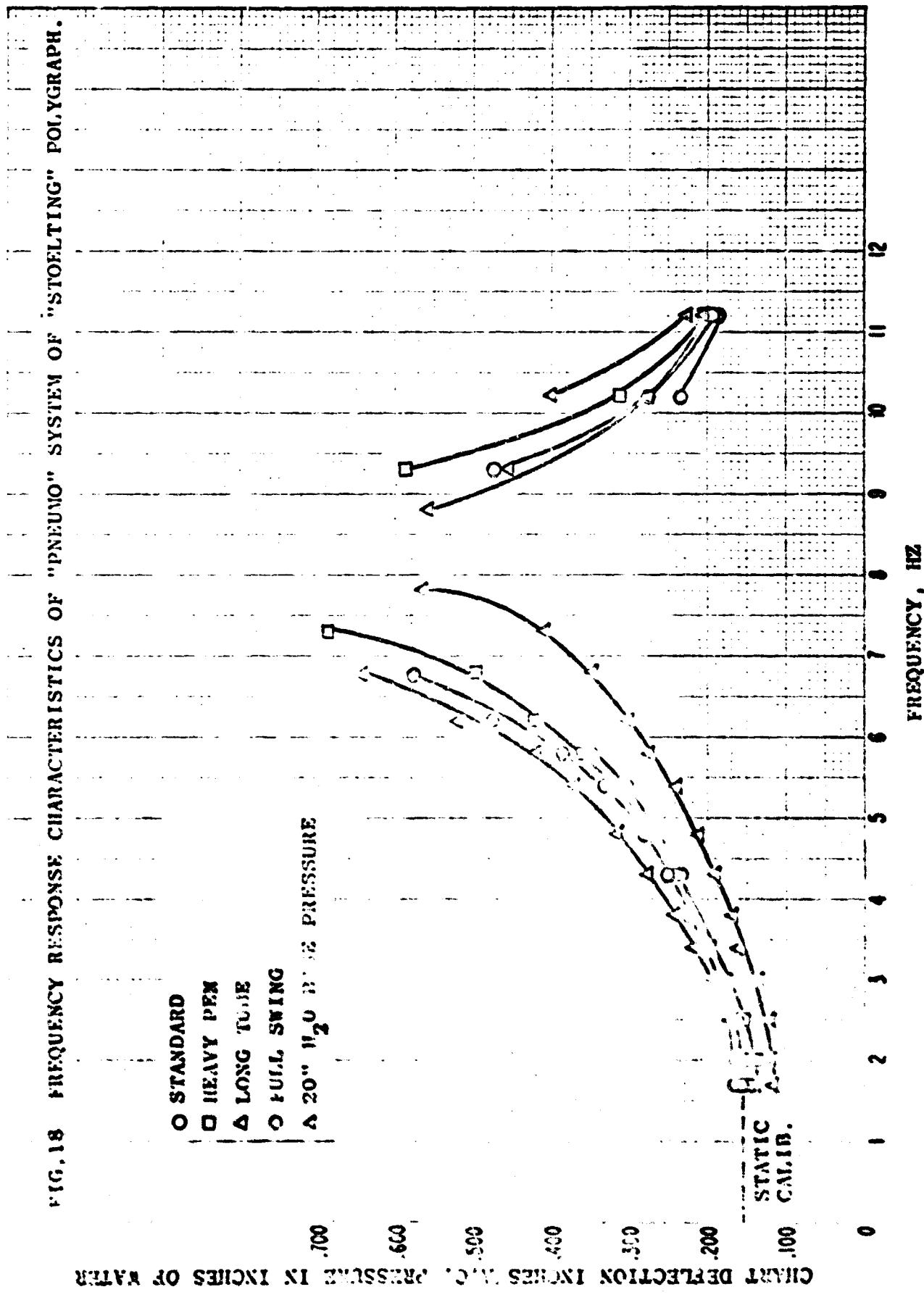
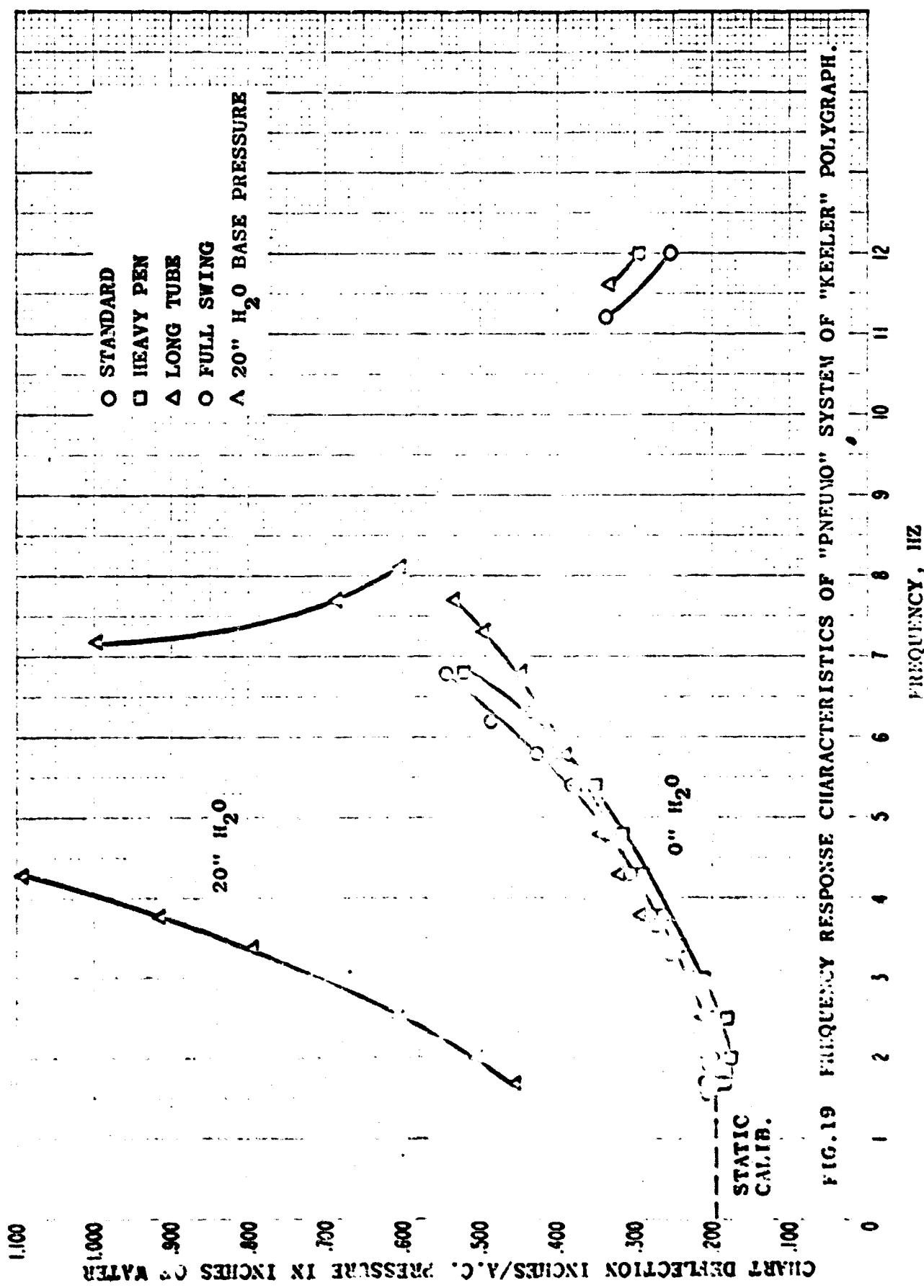


FIG. 17 SCHEMATIC OF DYNAMIC CALIBRATION SET-UP

FIG. 18 FREQUENCY RESPONSE CHARACTERISTICS OF "PNEUMO" SYSTEM OF "STORFLING" POLYGRAPH.





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FIG. 20 FREQUENCY RESPONSE CHARACTERISTICS OF "CARDIO" SYSTEM OF "STOELTING" POLYGRAPH.

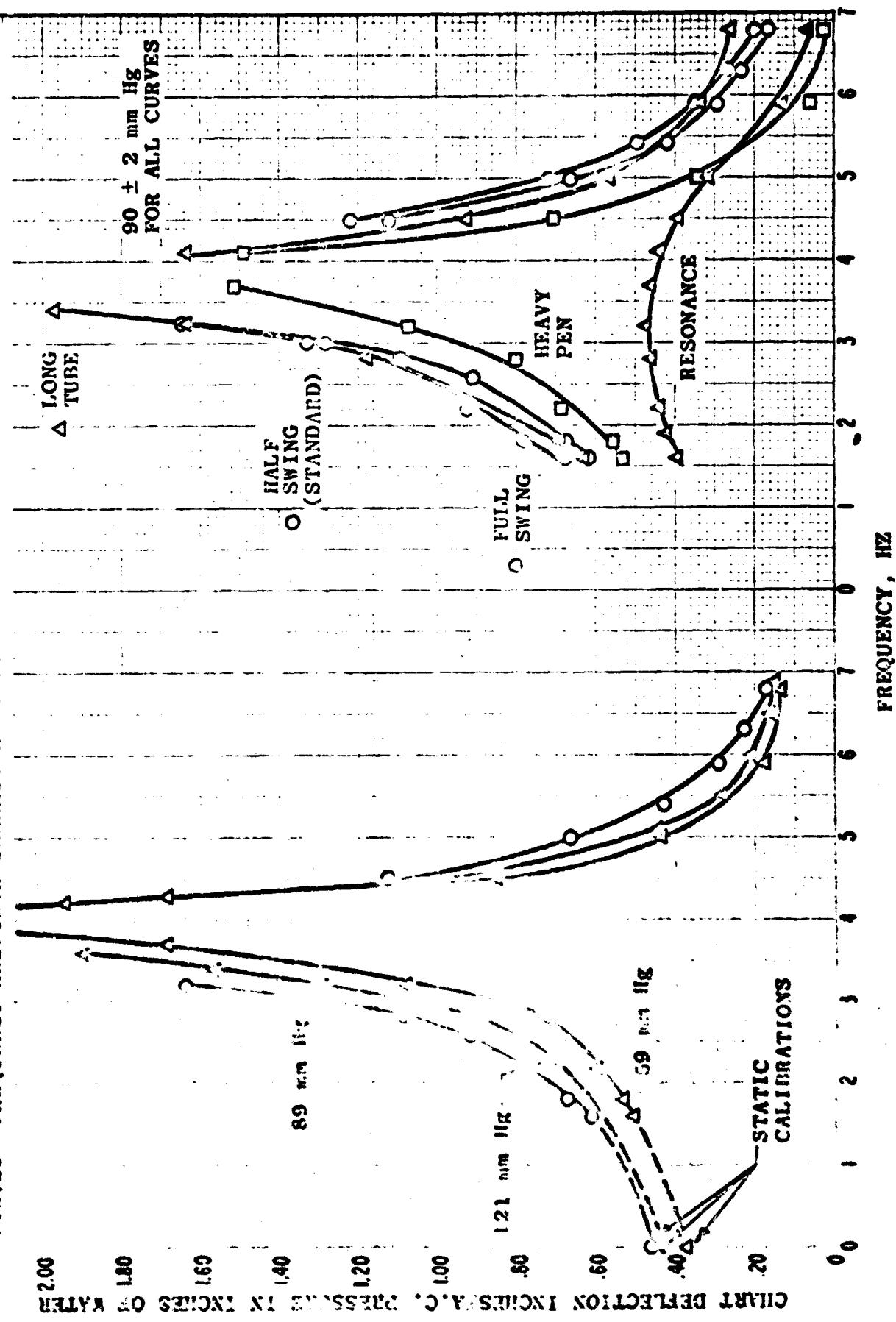
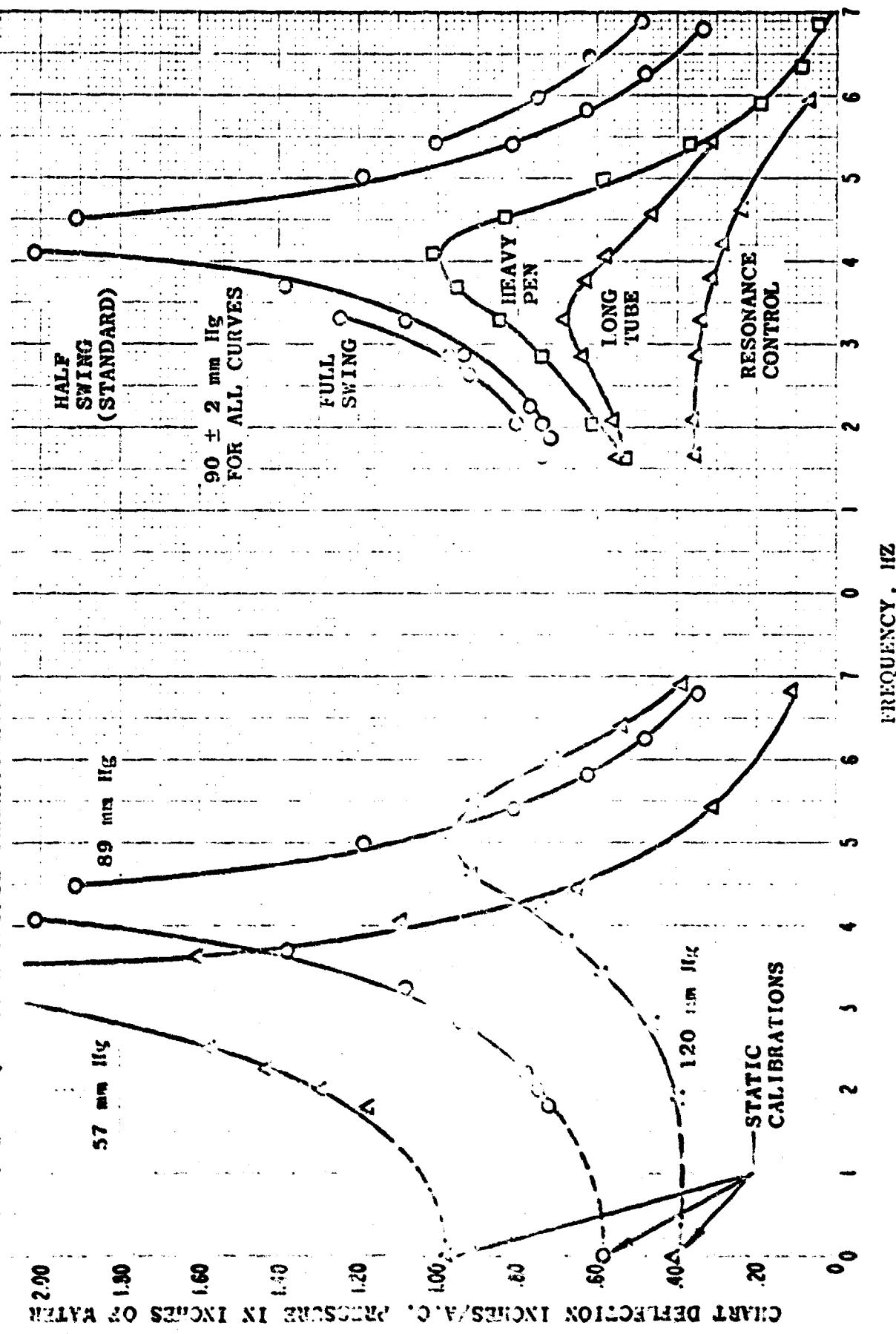


CHART DEFLECTION INCHES A.C. PRESSURE IN INCHES OF WATER

FIG. 21. FREQUENCY RESPONSE CHARACTERISTICS OF "CARDIO" SYSTEM OF "KEELER" POLYGRAPH.



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Definition of Terms

A few terms, which are used throughout this attachment, are defined here for convenience.

RO	Resistance connected across input terminals of GSR section which, unless exception is taken, is the "subject" resistance present when the ZERO-manual control is adjusted to cause pen to track centerline of strip chart, i.e., zero deflection.
ΔR	Change in resistance connected across input terminals of GSR section. ΔR represents a step change where the time required to change is so short compared to the polygraph response that the change may be considered instantaneous. Following the instantaneous change of magnitude ΔR, the resulting value of resistance remains fixed for a period of time.
Dwell Time	Period of time during which the "subject" resistance remains unchanged.
RO + ΔR	Total resistance connected across input terminals of GSR section and is considered the "subject" resistance. Test equipment provides step changes in "subject" resistance having the following fixed values:
	RO + ΔR RO (For ΔR = 0) RO - ΔR
"Subject" Resistance	Resistance connected across input terminals of GSR section. In general, "subject" resistance varies with time. The word, subject, appears in quotation marks throughout the text to indicate that the "subject" resistance is wholly ohmic and essentially independent of any potentials or currents which may be present.
k	Symbol for the prefix kilo, multiplier 1,000.
Ω	Symbol for the unit of resistance, ohm.

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division	A rectilinear measure of pen deflection corresponding to the major divisions of the strip chart. Each division is 1/4 inch. A plus sign indicates an upward or positive excursion from the zero center line and corresponds to a decrease in subject resistance. A negative sign indicates the inverse.
ZERO-auto	Mode of operation determined by a selector switch. Termed "Self Centering" for Keeler recorder Termed "Automatic Zero" for Stoelting recorder.
ZERO-manual	Mode of operation, alternate to ZERO-auto described above, determined by selector switch. Termed "Normal" for Keeler recorder Termed "Normal Zero" for Stoelting recorder.
SENSITIVITY	Operator adjustment. Termed "Reactivity" for Keeler recorder Termed "Sensitivity" for Stoelting recorder.
CENTERING	Operator adjustment. Termed "Subject Resistance" for Keeler recorder Termed "Centering" for Stoelting recorder

Attachment 2

I. INTRODUCTION

Attachment 2 provides the report of a study of the operational characteristics of the Galvanic Skin Resistance (GSR) Section of two polygraph recorders.

One of the purposes of the performance evaluation given in this attachment is to identify the important operational characteristics of the polygraph recorder. This has been done through an extensive series of measurements which have been summarized in the form of charts, graphs and tables presented below.

Consideration has also been given to the dependence of operational characteristics on major factors which influence performance.

An essential element in carrying out this work was the development of experimental instrumentation, tests and procedures. These are also described and discussed in the sections which follow.

II. DESCRIPTION OF POLYGRAPH RECORDER

Two polygraph recorders were supplied by the sponsoring agency for the purpose of study of the GSR sections. They are identified as follows:

Keeler Polygraph Model 6303, Serial 431
Manufactured by
Associated Research, Incorporated
3758 West Belmont Avenue
Chicago 18, Illinois.

Stoelting "Deceptograph" Model 22500,
Serial #7, Reg. BB#53293
Manufactured by
C. H. Stoelting Company
424 N. Homan Avenue
Chicago, Illinois 60624.

2.1 General

All appearances indicated that the recorders are

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new, unused, and of recent manufacture. Both instruments were received at NBS the same time, placed in operation together and have been treated in similar fashion throughout the entire period of testing program.

Since these and similar polygraph recorders are described in detail elsewhere,^{1,2,3}, this attachment will be limited to discussion of the electrical performance of the GSR Sections and, in particular, to the performance of the two polygraph recorders listed above.

2.2 Function of the GSR Section

The desired performance of the GSR Section is to provide a continuous analog record representing a function of the electrical resistance present across its input terminals. The output is an analog record on a strip chart.

The GSR Section may be considered as a measurement system consisting of three main parts; a Wheatstone bridge, an amplifier and an galvanometer pen movement. The bridge in the GSR Section, as in normal usage of a Wheatstone bridge, is balanced by an operator through adjustment of the ZERO control. This results in a zero-signal output from the bridge to the amplifier, and for a properly balanced system, the pen deflection remains at the zero centerline position. This setting of the ZERO adjustment provides the means for establishing a zero reference deflection regardless of "subject" resistance present as long as the "subject" resistance remains within the operating range of the recorder. Any change in "subject" resistance produces an unbalance and causes a voltage to appear at the output terminals of the bridge. The amplifier, in turn, drives the pen galvanometer producing a torque which increases with the unbalance voltage. This results in deflection of the pen tracing on the strip chart.

In an ideal system designed to measure resistance the relationships between the input and output would be linear and sufficiently responsive to changes in

1 "Recording Lie Detector AN/USS-2C," Department of the Army Technical Manual TM 11-5538Z, 23 March, 1957.

2 "Recording Lie Detectors AN/USS-2C and AN/USS-2D," Department of the Army Technical Manual TM-11-5538A/C1, 30 October, 1958.

3 See literature from the manufacturer.

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resistance so as to follow or track these changes. In addition, the ideal system would not be responsive to other variables.

The tests conducted at NBS provide a quantitative study of the polygraph recorders with the underlying assumption that the purpose of the system is to approach the performance of the ideal system described above. This simplifying assumption allows the performance of the polygraph recorder to be examined in familiar terms of accuracy or error compared to an ideal model. This treatment does not take into consideration the desirability or need for deliberate non-linear response or other enhancements which might best serve the intended application. It is beyond the purview of the present study to include such factors, for example, as operator interpretation of the strip-chart record and the nature of the electrobiological signals presented to the input.

III. EVALUATION PLAN

In order to establish a rationale for planning the experimental work which would lead to an evaluation of the performance of the GSR Section the operating characteristics have been divided into three general classes; static, dynamic, and drift characteristics. Furthermore, each in turn, may be influenced by three broadly classified factors; (1) calibration and other adjustments not part of operator's normal routine, (2) operator controls and adjustments, and (3) external factors normally beyond control of the operator. In spite of certain aspects of these classifications being somewhat arbitrarily and not completely independent, they have proven to be a valuable aide in planning and carrying out this work.

3.1 Operating Characteristics

The relationship between input variables and the chart record determines the operating characteristics. These characteristics are dealt with as a function of time in three classifications which must necessarily overlap somewhat.

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3.1.1 Static Characteristics

These characteristics apply only when the input variable is fixed and sufficient time has been allowed for the output to just reach its final value. A shorter time would involve dynamic characteristics and a longer time may involve drift characteristics.

Considerations of static characteristics include the response of the system to resistance, the presence of dc voltage produced by the input circuit (Wheatstone bridge) and the response of the system to dc voltage.

3.1.2 Dynamic Characteristics

Dynamic characteristics concern response to changes in the input variable where the variable does not remain stationary for long periods of time compared to the time required for the recorder to reach an equilibrium. The maximum period of time to reach equilibrium is approximately 20 seconds for the Keeler recorder and 6 seconds for the Stoelting recorder when ZERO control is set to "automatic" position.

The response to a variable-frequency sinewave input voltage is used to determine pass band characteristics over the frequency spectrum of interest. Time constants and damping characteristics are explored.

In certain instances the dynamic characteristics are strongly dependent upon variables such as pen deflection and pen-weight adjustment. The effects of such variables are included in the study.

3.1.3 Drift Characteristics

Drift characteristics concern mainly stability and deal conceptually with response in the time domain between the static and dynamic characteristics described above. Stability during periods of time ranging from minutes to hours and daily repeatability for several weeks have been measured and reported.

3.2 Factors Affecting Operation

The three factors affecting operation are listed

Attachment 2

and described below. The manner and extent of their influence on the separate operating characteristics have been investigated and those dependencies of significance are reported.

3.2.1 Calibration Adjustments

Prior to the beginning of a rather extensive testing program, the GSR Sections were examined and minor adjustments made if necessary. The adjustments included mechanical and electrical balance and sensitivity adjustments. These and other adjustments are described in detail under Section V., CALIBRATION.

Test Procedures

The calibration adjustments provided assurance that the recorders were operating properly in accordance with information available in the instruction books provided by the manufacturer with his respective recorder. The associated Technical Manuals were also of value.

3.2.2 Operator Controls and Adjustments

The controls and adjustments which are normally available for the operator to use strongly influence the chart record pattern. The two manufacturers use different terms to describe controls having the same function. The terms adopted for use in this report are as follows:

This Attachment	Keeler	Stoelting
ZERO-auto	"Self Centering"	"Automatic Zero"
ZERO-manual	"Normal"	"Manual Zero"
SENSITIVITY		
CENTERING		

Warm-up time effects were also considered to fall under operator control.

3.2.3 Other Factors

Other factors deal mainly with operating conditions

Attachment 2

such as line voltage, hum and pick-up and grounding, etc. No environmental tests involving ambient temperature and relative humidity were included. Unavoidable room temperature variation ranged from 70° to 78°F and associated relative humidity variations from approximately 10% to 40% were present through the six-weeks test period.

IV. TEST SET-UP

In setting up both polygraph recorders a number of precautions were taken. Line voltage was regulated and set to 115 volts. Each recorder was isolated from power ground with individual isolation transformers and each piece of line-operated equipment was similarly isolated so as to minimize the effects of line borne interference, and to minimize the presence of ground currents between equipment grounds. Although these precautions were maintained throughout the test period, no change appeared in recorder performance when the isolation transformers were removed and individual recorders operated in normal fashion without connection to line-operated test equipment.

The photograph of Fig. 1 shows the test set-up for the input connections to the recorder under test. The possible effects of stray pick-up from hum sources, rf interference, etc. were minimized through careful shielding and grounding. Notice that the recorded sits on a metal sheet which provides a common local ground. The chassis of each equipment is connected to the common ground through short lengths of AWG #6 welding cable with spade lugs and wing-nut clamps shown in the foreground of the photograph. Unless noted otherwise, all tests were conducted with the 60-Hz power line voltage, regulated and maintained at 115 volts, and the polygraph recorders were turned "on" for a warm-up period of at least 30 minutes before beginning tests.

No difficulty was experienced in using the test set-up shown as long as the input leads to the recorders were neither moved nor touched nor approached to within a few inches during a test run. An attempt was made however, to survey the susceptibility of the recorders to pick-up under the test set-up used.

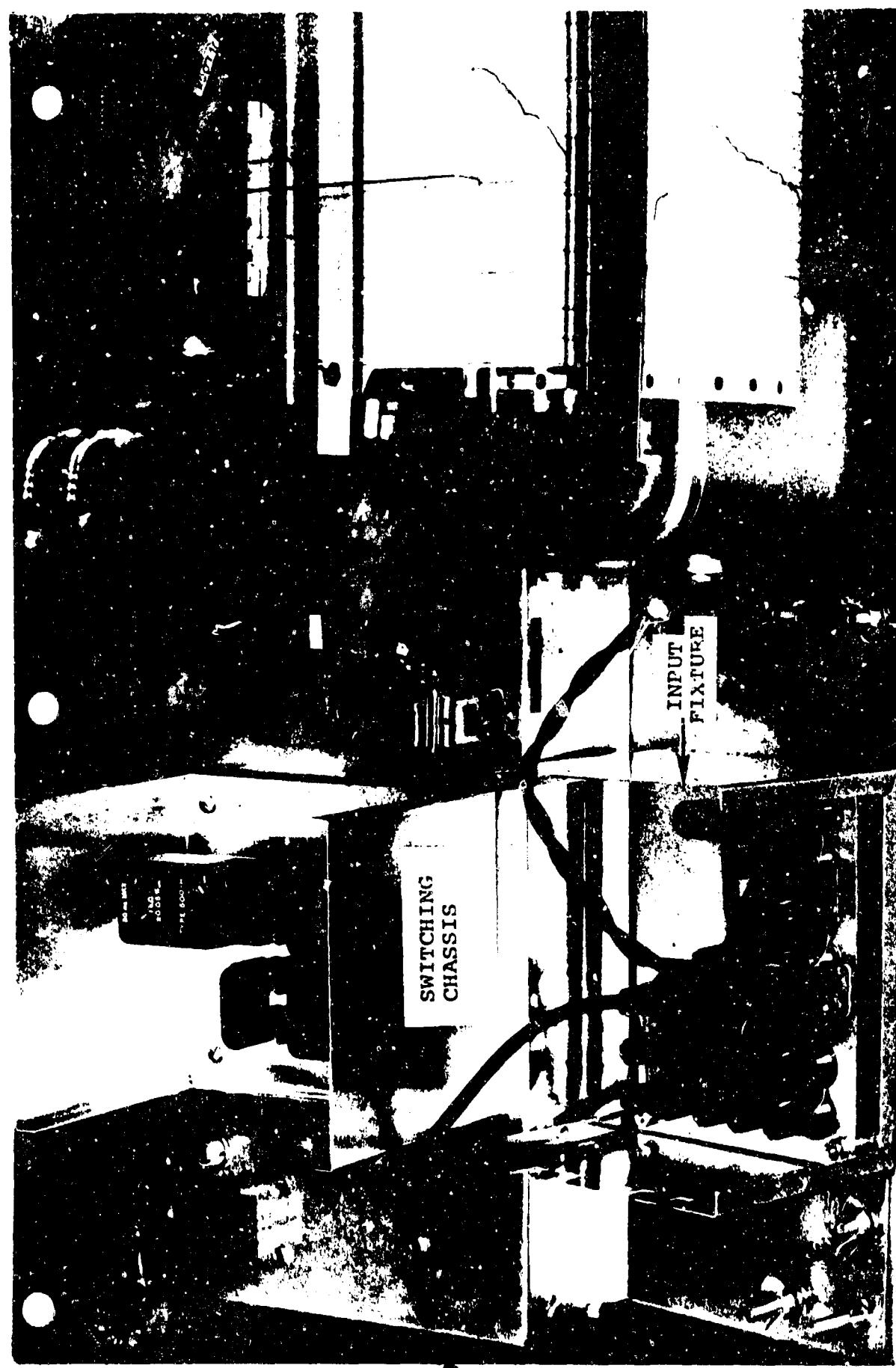


FIG. 1 INPUT EQUIPMENT

Attachment 2

4.1 Review of Sensitivity to Pick-up

These tests are highly subjective; they represent the conditions existing for the NBS test set-up. It would not be unreasonable to assume however, that similar observations would be expected for other normal operating conditions.

The Keeler recorder was set as follows (see definition of terms):

RO = 100 k Ω
ZERO-manual
SENSITIVITY set to maximum.
CENTERING adjusted for zero pen deflection.

The tests consisted of touching each of the input leads with the finger tip while not in contact with ground or any other metal object. Hum voltage on the lead in question was measured and the resulting pen deflection observed.

Neither of the input leads was connected to chassis ground. The low-side conductor was insensitive to touch with the finger tip. Although this procedure caused a 45 millivolt, peak-to-peak 60-Hz voltage to appear between the low side conductor and chassis ground, it produced no change in pen deflection. Touching the high-side conductor caused a somewhat smaller hum voltage to appear and a pen deflection of approximately one-half of a major chart division. The observed low sensitivity to hum was expected because the recorder design includes filters to reduce the effects of hum present on the input leads, and perhaps more importantly, the amplifiers are primarily designed to be sensitive to dc and very low-frequency signals only. The presence of large hum voltages however, would tend to block or overload the amplifiers and result in severe a linear performance. This fault was not apparent.

The same operating conditions, as described above, were set for the Stoelting recorder. The low-side lead was connected to chassis ground and was observed to be insensitive to contact with the finger. The high-side lead was very sensitive to the presence of the finger tip; touching the insulation jacket caused a two-division deflection of approximately four divisions even though the sensitivity control reduced to 10% of

Attachment 2

maximum. This latter observation compared with the sensitivity of the Keeler recorder leads to an estimate of the relative sensitivity of approximately 150 to 1, i.e. the Stoelting is approximately 150 times more sensitive to hum under the measurement conditions described. The relatively high sensitivity to hum stems from the use of a synchronous diode chopper in the input of the amplifier which treats ac signals having odd multiples of power line frequency in essentially the same manner as the desired dc input signal. Ordinarily this sensitivity to hum interference is not troublesome when operated as intended because the body of the subjected is in contact with the chassis ground lead and otherwise isolated. The sensitivity to hum is troublesome however, when conducting tests and in following calibration procedures. The extent of the interference and the recommendations are given in the section which describes calibration.

V. CALIBRATION

Each recorder was carefully calibrated prior to initiation of tests so as to be reasonably certain that it was operating in accordance with available specifications. Throughout the entire test period a calibration-check procedure was followed to determine that the recorders continued to operate satisfactorily and, at the same time, to establish a measure of drift of the more important operating characteristics.

5.1 Calibration of the Keeler Recorder

Throughout the calibration procedures it was found necessary to tap the chart paper as adjustments were made so as to overcome pen drag friction. If this were not done, the pen would be insensitive to fine adjustments.

5.1.1 Mechanical Balance

Before turning the amplifier on, the mechanical balance of the pen galvanometer was checked and adjusted to obtain a center line (zero) deflection on the chart paper. The adjustment was made by inserting a nonmagnetic screwdriver through a hole in the top panel near the galvanometer so as to engage an adjustable arm located about three inches below the panel surface.

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5.1.2 Electrical Balance

To adjust for an electrical balance the recorder was first turned "on" and allowed to warm-up for at least thirty minutes. With the ZERO-manual mode of operation, the input connector was unplugged so as to insert a 51-k Ω resistor across the input terminals as intended for calibration purposes. The CENTERING control was adjusted to obtain zero pen deflection. Then SENSITIVITY control was varied from minimum (dial reading "0") to maximum ("10") while variable resistor R17 shown in Figure 2 was adjusted to a point where pen deflection was not affected by change in SENSITIVITY and at the same time, the pen deflection remained at zero center. This procedure balances the system for the given input condition.

5.1.3 Sensitivity

Following the instructions given in Note 2 of the Troubleshooting Chart in the Operating Instruction Manual, Model 6303 Polygraph, the 51-k Ω calibration resistor was inserted across the input terminals, the pen was centered using the CENTERING control while in the ZERO-manual mode of operation. With the SENSITIVITY control set at "5," 50% of maximum, the CENTERING control was changed one division, (corresponding to an indication of a 5-k Ω change in subject resistance) which, according to the instructions, should cause a full-scale pen deflection. A full-scale pen deflection is not a satisfactory indication for calibration of sensitivity because the pen deflection at the extreme end of the scale enters a non-linear region of operation. (See Figures 3A, 3B, and 3C.) Furthermore, the one-division change in the setting of the CENTERING dial, which is recommended in the manual, is a change too small to be readily reproducible.

For these reasons the method for calibration of sensitivity recommended in the manual is considered wholly unsatisfactory for our purposes.

5.1.4 Sensitivity, an Alternate Calibration Procedure

In place of the internal calibration resistor, the leads from the recorder were connected to an external 50-k Ω resistor. Instead of changing the CENTERING dial one scale division as directed, which is equivalent to an unbalance of 5 k Ω , the

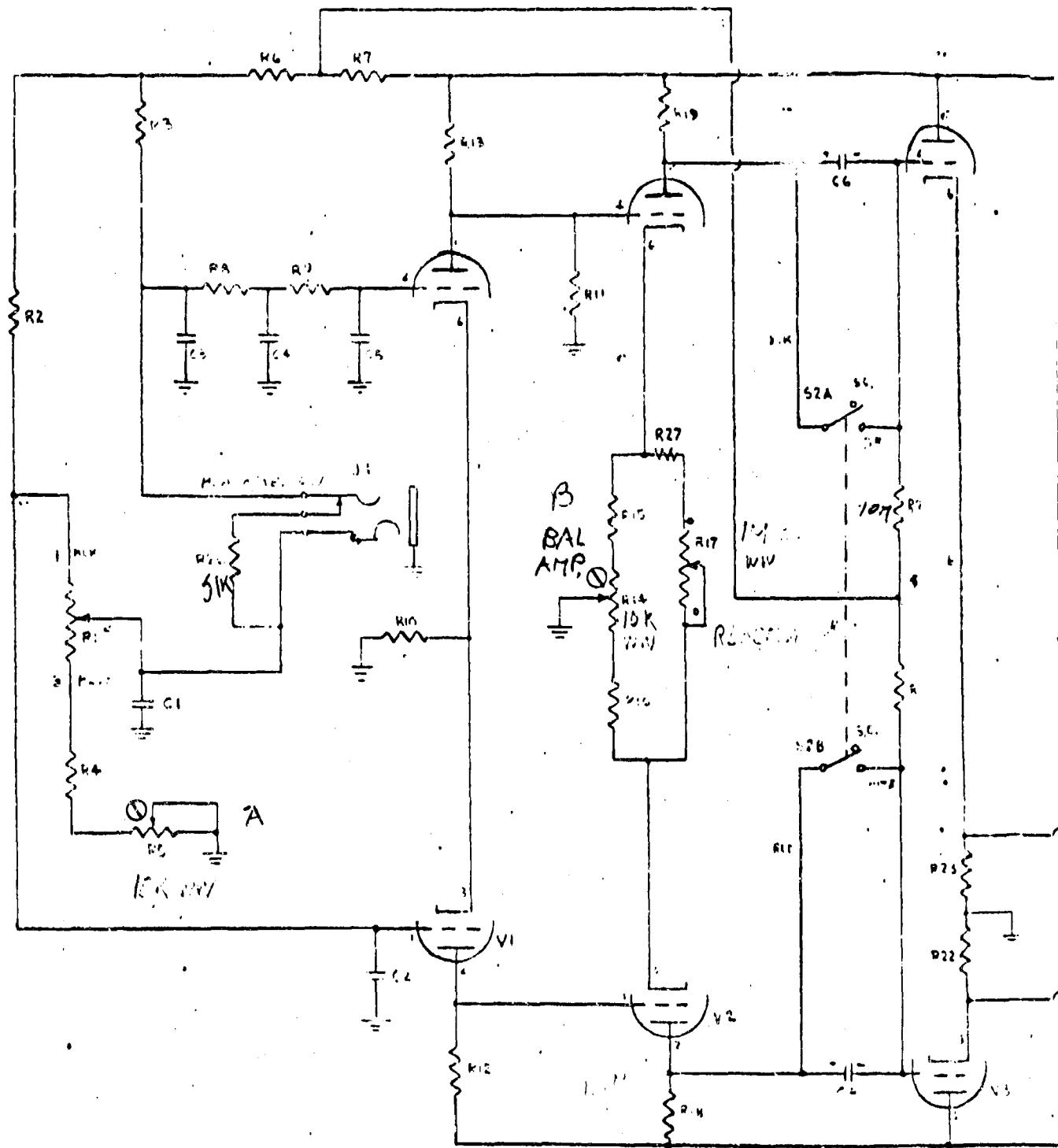
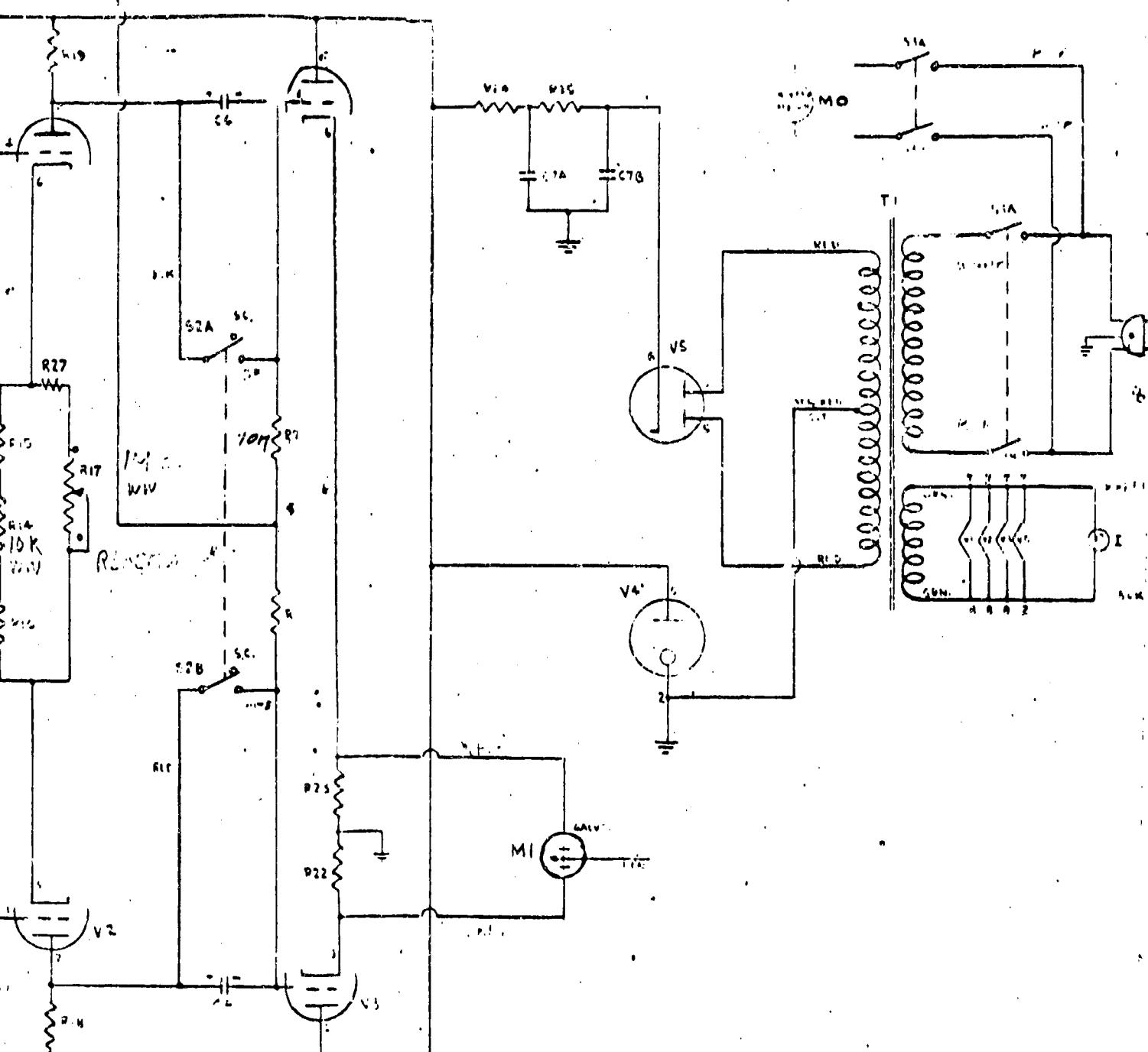


FIG. 2 SCHEMATIC DIAGRAM OF KEEBLER



SCHEMATIC DIAGRAM OF KEELER RECORDER

Attachment 2

subject resistance was reduced by 5 k Ω . The pen was adjusted with the CENTERING control to a deflection of -5 divisions while 50 k Ω was present at the input and while SENSITIVITY was set at the recommended "5" position. Then with 5 k Ω subtracted from the subject resistance, R5 (also designated as A) was adjusted so as to obtain a +5 division pen deflection. The swing from -5 to +5 divisions is equivalent to a deflection from zero center to full-scale with the advantage that the pen deflection remains in an essentially linear region of operation.

Since much of this report deals with highly repetitious descriptions of relationships between settings of various controls, changes in subject resistance, pen deflection, etc., a notation has been adopted which is intended to order and simplify the description of operating conditions. The "Alternate Calibration Procedure" described in the above paragraph is repeated here to introduce, by way of an example, the format and notation which will be used. The terms are described in the earlier section, "Definition of Terms."

Initial conditions:

RO	50 k Ω
ZERO	manual
SENSITIVITY	50% maximum
CENTERING	-5 divisions

After the above conditions were established, the subject resistance was reduced by an amount ΔR , ($\Delta R = -5 \text{ k}\Omega$)

$$RO + \Delta R = 15 \text{ k}\Omega.$$

The system sensitivity was then calibrated by adjustment of R5, in Figure 2, so as to obtain a pen deflection of +5 divisions.

The equivalence of this alternate procedure was verified by obtaining excellent agreement with the second procedure listed in Note 2 of the manual wherein it is stated that a 10-k Ω change should produce a 10-divisions change in pen deflection for the SENSITIVITY control set to zero (minimum).

SP
10
KEELER POLYGRAPH
MODEL 6303, SERIAL 431

RO 3kΩ
SENSITIVITY Max.
ZERO Manual

DEFLECTION IN DIVISIONS (1/16")

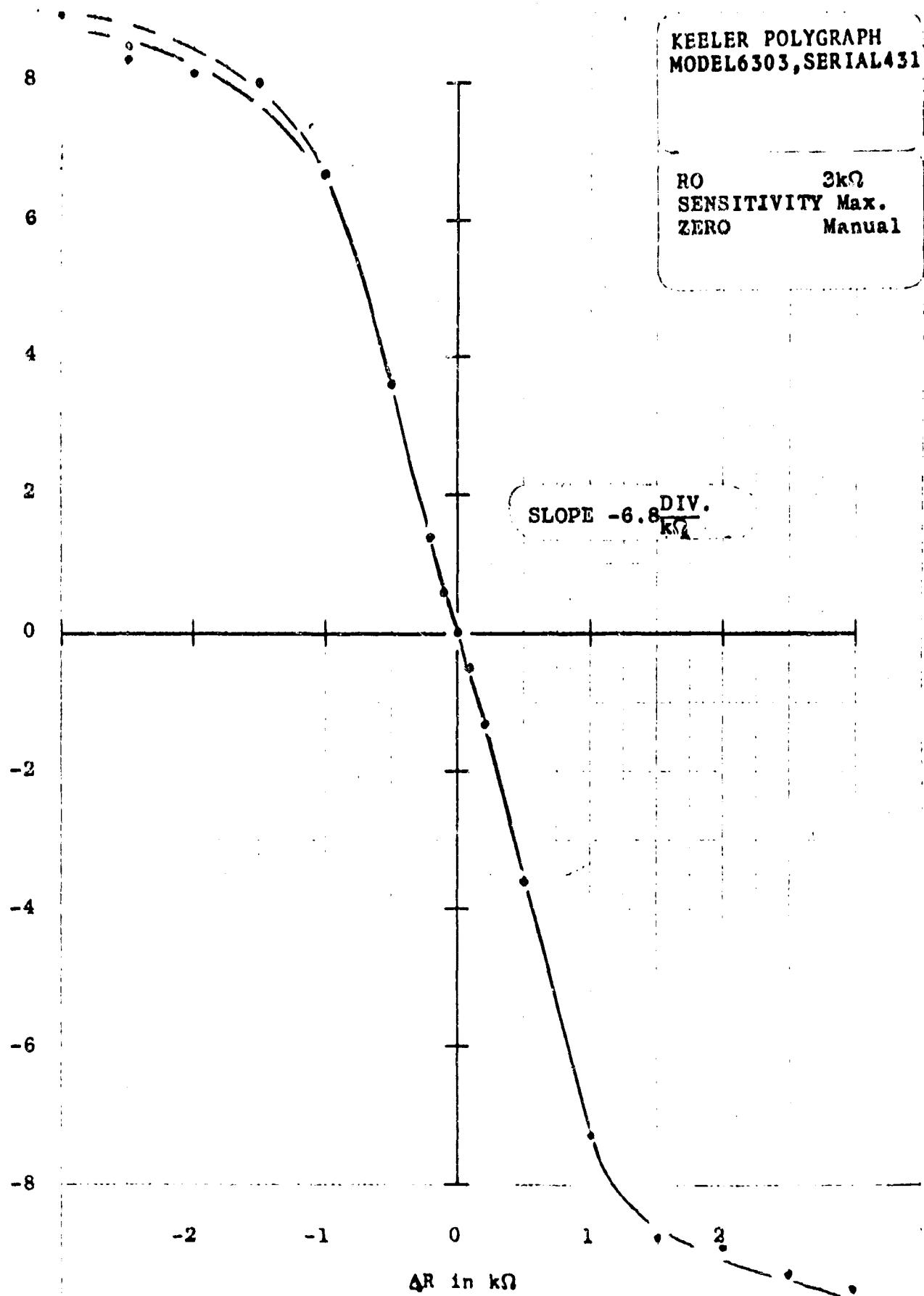


FIG. 3A Pen Deflection as a Function of Change in "Subject" Resistance for $RO = 3k$

B
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KEELER POLYGRAPH
MODEL 6303, SERIAL 431

RO 100k Ω
SENSITIVITY Max.
ZERO Manual

DEFLECTION IN DIVISIONS (1/4")

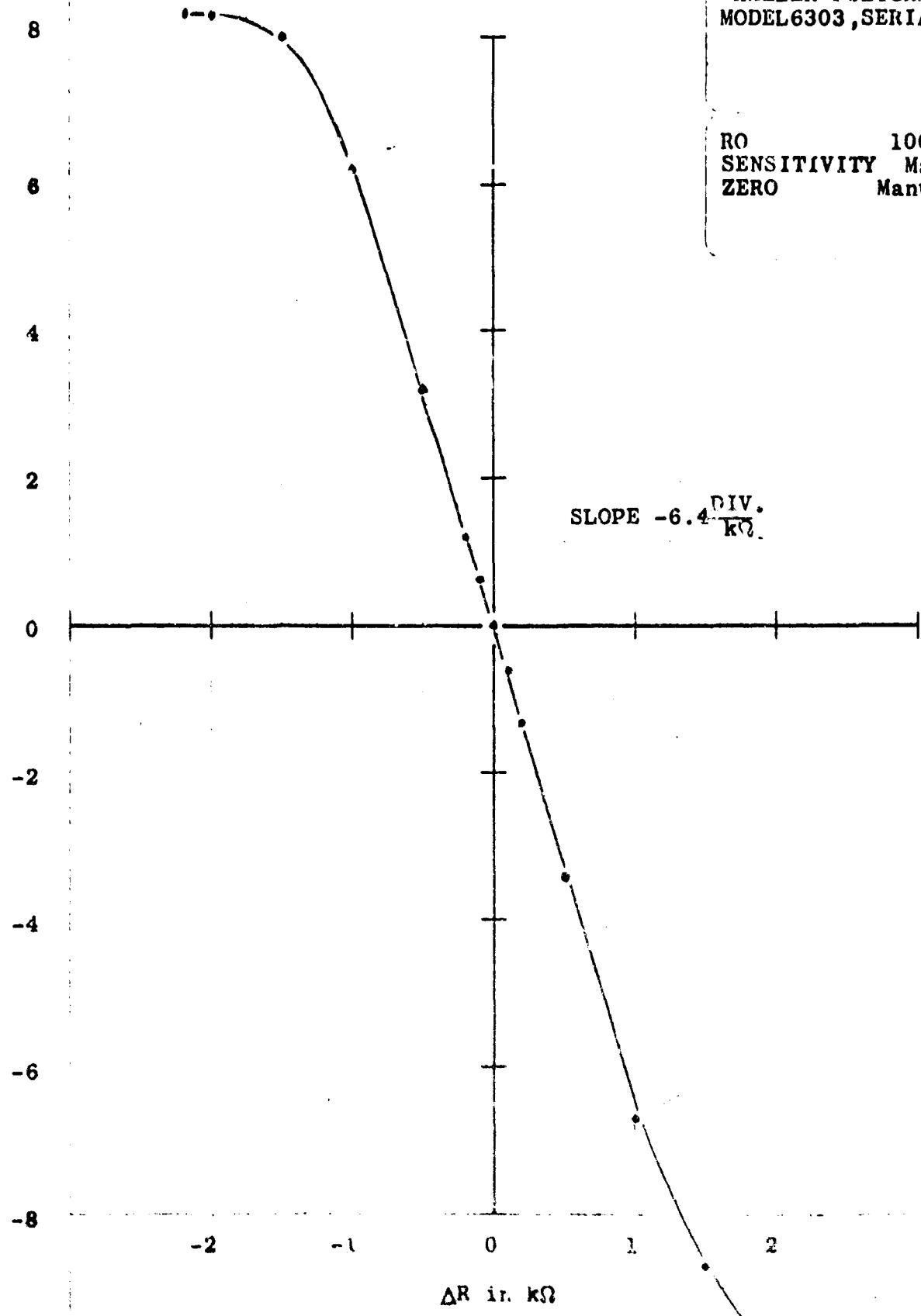


FIG. 3B PEN DEFLECTION AS A FUNCTION OF CHANGE IN "SUBJECT" RESISTANCE FOR RO = 100k Ω .

KEELER POLYGRAPH
MODEL 6303, SERIAL 431

RO 240k Ω
SENSITIVITY Max.
ZERO Manual

DEFLECTION IN DIVISIONS (1/4")

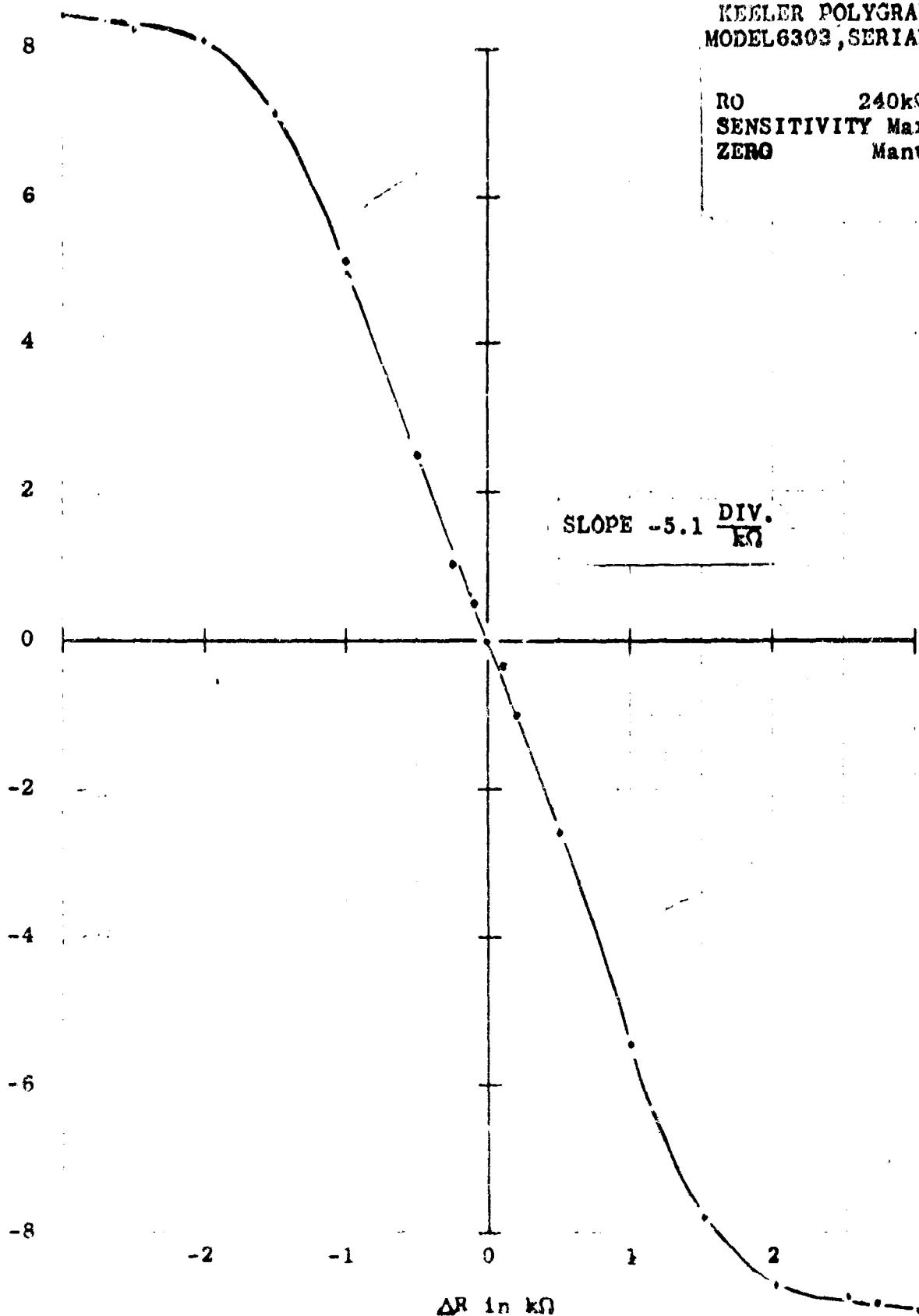


FIG. 3C PEN DEFLECTION AS A FUNCTION OF CHANGE IN "SUBJECT" RESISTANCE FOR RO = 240k Ω .

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Attachment 2

5.1.5 CENTERING Control Dial

A five-turn variable resistor control is provided to permit the operator to balance the Wheatstone bridge in the input circuit and thus zero-center the pen. A scale associated with this control is calibrated to indicate the magnitude of the subject resistance directly in kilohms. The calibration for one point on the scale of this dial may be obtained by adjusting R5 to obtain zero pen deflection for a given value of subject resistance. This was done for a subject resistance of 100 k Ω . The dial reading error at this point is thereby reduced to zero but there remains an unavoidable tracking error which is given in Table I below:

TABLE I
Tracking Error of Subject Resistance Dial

SUBJECT RESISTANCE $k\Omega$	DIAL READING INDICATING SUBJECT RESISTANCE	ERROR	
		DIAL READING	FRACTIONAL
(balance unattainable)			
2	0	-2	-100 %
5	3	-2	-40 %
10	8	-2	-20 %
20	18	-2	-10 %
50	48	-2	-4 %
100	100	0	0
150	150	0	0
200	202	+2	1.0%
220	223	+3	1.4%
240	243	+3	1.2%
250			
(balance attainable)			

This fractional error was determined from the equation

$$\text{Fractional Error} = \frac{(\text{Dial Reading}) - (\text{Subject Resistance})}{(\text{Subject Resistance})} \times 100 \%$$

Attachment 2

The manufacturer's specification for the Model 6303 Polygraph, Bulletin 6-1.4, specifies that the subject resistance range is 0 to 250 k Ω . The attainable range, as indicated in the table, was 2 k Ω to approximately 244 k Ω .

The entire calibration procedure was repeated to be certain that all requirements were met. At no time after this, throughout the remainder of this study, were any further internal or calibration adjustments made. A series of observations was made however, which provided a measure of stability of the mechanical balance and sensitivity. The results are discussed under section VIII which treats the subject of drift.

5.2 Calibration of the Stoelting Recorder

The general procedure for calibration is similar to that outlined for the Keeler recorder in Section 5.1. There are however significant differences in the details, especially regarding calibration of sensitivity.

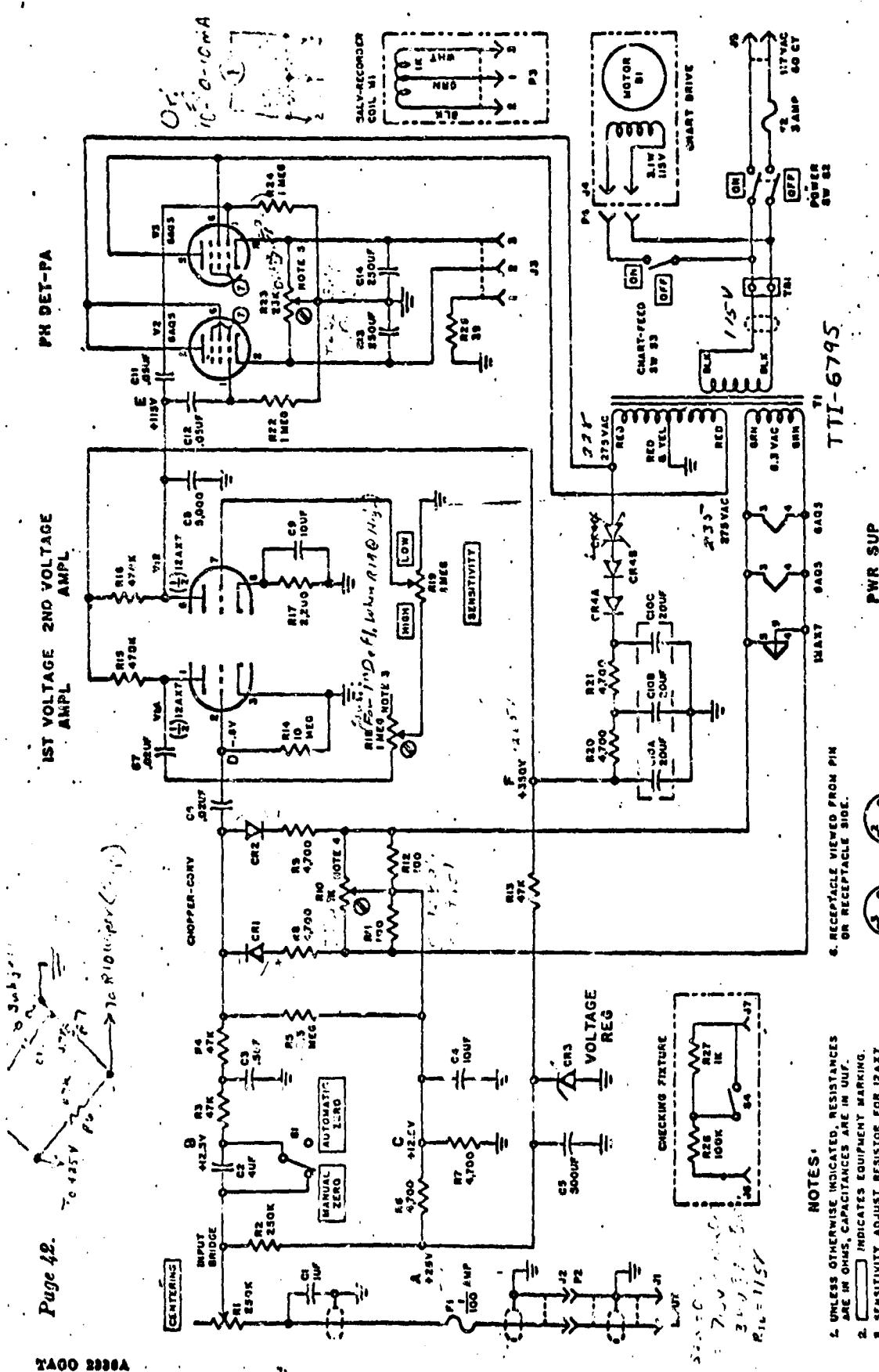
Instructions given in the manufacturer's manual under the major heading "G.S.R. Components-Amplifier and Galvanometer" with subsection "Troubleshooting--G.S.R. Components" paragraph 10, 10A, and 10B were very helpful for calibration of the recorder.

5.2.1 Mechanical Balance

With the recorder turned off, the pen deflection was observed to be approximately one-half division (1/8 inch) above the strip chart center line. Excessive end play in the pen cradle allowed lateral pen motion of one-quarter division. The excessive end play was minimized by springing the cradle arms together. Then the mechanical balance was adjusted to provide center line tracking.

5.2.2 Electrical Balance

The electrical balancing procedure follows that given under paragraph 10-A entitled "To Adjust G.S.R. Pen Alignment." With ZERO-auto mode of operation and SENSITIVITY adjusted to minimum, the output tubes were balanced by adjusting variable resistor R23 in Fig. 4 so as to cause pen to track on the zero center line. Then SENSITIVITY was set to maximum and the diode balance control, R10 adjusted in a similar manner. Finally, the SENSITIVITY control was rotated between minimum to maximum to be certain that electrical balance had been achieved.



NOTES:

- UNLESS OTHERWISE INDICATED, RESISTANCES ARE IN OHMS, CAPACITANCES ARE IN UF.
- INDICATES EQUIPMENT MARKING.
- Sensitivity adjust resistor for 12AX7 VOL. AMP. SECTION.
- BALANCING RESISTOR FOR SQUARE WAVE OUTPUT OF CHOPPER SECTION.
- BALANCING RESISTOR FOR V2, V3 STAGES.
- RECEPABLE VIEWED FROM PIN OR RECEPTACLE SIDE.

FIG. 4 SCHEMATIC DIAGRAM FOR STOEBLING RECORDER

Attachment 2

5.2.3 Sensitivity

Again the instructions in paragraph 10-B, "To Adjust G.S.R. Sensitivity" were followed. The following initial adjustments were made:

RO	101 kΩ
ZERO	manual
SENSITIVITY	maximum
CENTERING	zero pen deflection

The subject resistance was changed by $\Delta R = -1 \text{ k}\Omega$, thus

$$R_0 + \Delta R = 100 \text{ k}\Omega$$

and the sensitivity of the system calibrated by adjusting R18, Figure 4, to obtain a pen deflection of +4 divisions (one inch). Sensitivity thus obtained is -4 divisions/kΩ.

It should be noted that comparable test conditions applied to the calibrated Keeler recorder indicate sensitivity of approximately -7 divisions/kΩ.

5.2.4 Uncertainties in use of "Checking Fixture" for Calibration

The sensitivity calibration procedure recommended in the instruction manual and in the technical manual, TM 11-5538 C1, calls for plugging the input leads into a "checking fixture" supplied with the recorder and shown in Figure 4. Depressing a switch changes subject resistance from 101 kΩ to 100 kΩ which should produce a corresponding change in pen deflection of +4 divisions. It was found that the resulting pen deflection was also affected by whether or not the operator touched the checking fixture chassis and if so, whether or not the operator or chassis was grounded. The physical spacing between switch and chassis would seem to leave the unwary operator's touching or not touching the chassis up to chance. The most serious error occurs if both the operator and case are ungrounded and the operator touches the fixture chassis. This produces a one-half division (decrease) in pen deflection. Grounding either the operator or the chassis essentially eliminates the problem.

It is recommended that an external checking fixture not be used, but rather the components

of the checking fixture be mounted for use under the GSR front panel and thus provide effective shielding and grounding. The physical layout should be such that the operator neither touches nor comes in close proximity to the input leads.

5.2.5 CENTERING Control

Unlike the Keeler recorder, the Stoelting does not have a calibrated dial and therefore cannot be conveniently used to measure subject resistance. The CENTERING control however, is a ten-turn multipot which allows the centering adjustment to be easily made.

The full range CENTERING is specified as zero to 250 k Ω . The measured range was zero to 244 k Ω .

As was done for the Keeler recorder, the entire calibration procedure was repeated and a series of observations instituted for determination of stability which is discussed in section VIII.

No further calibration adjustments were made throughout the remainder of this study.

VI. STATIC CHARACTERISTICS

The static characteristics deal with fixed input signals and the corresponding final values of pen deflection without consideration given to the time it takes to reach final value nor to transient pen deflections. The latter elements are discussed under dynamic characteristics.

The recorder is sensitive, as intended, to subject resistance and its changes. It is also sensitive to dc voltage input. This section, therefore, reports on both responses.

Numerous graphs are used to summarize characteristics involving pen deflection throughout this report. Pen deflection is measured on the strip chart record in terms of the number of chart divisions from the zero center line, interpolated to the nearest 1/10 division. This rectilinear scaling procedure is convenient to use because the strip chart scaling lines are rectilinear. It would have been more proper to have scaled the angle of deflection but the differences between the two scaling procedures are negligible except, perhaps, for the largest excursions. At the extreme chart edge for a ten-division deflection the rectilinear scaling procedure used results in a scaled value which is too small be less than 0.2 divisions or 2% for the Stoelting

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7-inch pen. For the Keeler's 4 2/3-inch pen, the error is less than 0.4 divisions or 4%. Since these errors for extreme deflections are not large, and decrease rapidly with decrease in deflection, they are essentially not significant.

6.1 Static Characteristics of Keeler Recorder

The serial static characteristics of the Keeler Recorder will be followed by a similar discussion of the Stoelting.

6.1.1 Response to Change in Subject Resistance

Deflection versus change in subject resistance was plotted for three different input conditions; R_0 equal to 3 k Ω in Figure 3A, R_0 equal to 100 k Ω in Figure 3B and R_0 equal to 240 k Ω in Figure 3C. The straight line portion of the plots shows the region of linear response and the slope of the straight line is a measure of sensitivity.

The slope or sensitivity expression includes a negative sign to indicate an inverse relationship, an increase in ΔR results in a decrease or downward pen deflection, and vice versa.

Sensitivity decreases as R_0 increases -

R_0 k Ω	Sensitivity DIV./k Ω
3	-6.8
100	-6.4
240	-5.1

Unless the dependence of sensitivity on R_0 is considered, a determination of change in subject resistance on the basis of pen deflection alone could result in an error as large as approximately 30%.

6.1.2 DC Voltage Appearing Across Subject Resistance

The Wheatstone bridge in the input circuit provides the conversion from resistance to voltage. When a subject resistor is connected across the input terminals this resistor is inserted in the "unknown" terminals of the bridge and a current passes through the resistor thereby producing a voltage across the resistor. This

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voltage is present at all times, even though the bridge may be balanced by adjustment of the CENTERING control. The potential across the subject resistor was measured using a slide-back voltmeter principle wherein a potential source was applied across the subject resistor and the voltage of this source adjusted until a value was obtained which when maintained, produced no change in pen deflection regardless of whether or not it was connected across the subject resistor. In effect, this technique is equivalent to using an infinite impedance voltmeter.

A plot of dc voltage appearing across the input terminals versus subject resistance for zero deflection is given in Figure 5. The zero deflection or balanced bridge condition minimized the effect of the presence of amplifier or detector loading. For this condition, the current present in the subject resistor is constant and independent of subject resistance. For the Keeler recorder the current is 26 μ A. (For the Stetling, it is 40 μ A.)

When the bridge is not balanced and an "unbalance" voltage is applied to the amplifier terminals, the amplifier input has a loading affect which causes sensitivity to be dependent upon subject resistance as reported in the previous section. The magnitude of the loading is determined in the following section.

6.1.3 Response to Applied DC Voltage

Steps of a dc voltage were applied across a ten-ohm resistor connected in series with RO. In effect, this represented a zero-impedance voltage generator connected in series with RO. The relationship between pen deflection and dc input voltage in series with RO is shown in Figure 6. The response is essentially linear over a range of nearly 7 divisions or approximately 30 mv. The slope varies with RO as shown in the graph, sensitivity decreasing as RO increases. The decrease in sensitivity is due to the loading effect of the amplifier. The amplifier input resistance calculated from these data is approximately 570 k Ω .

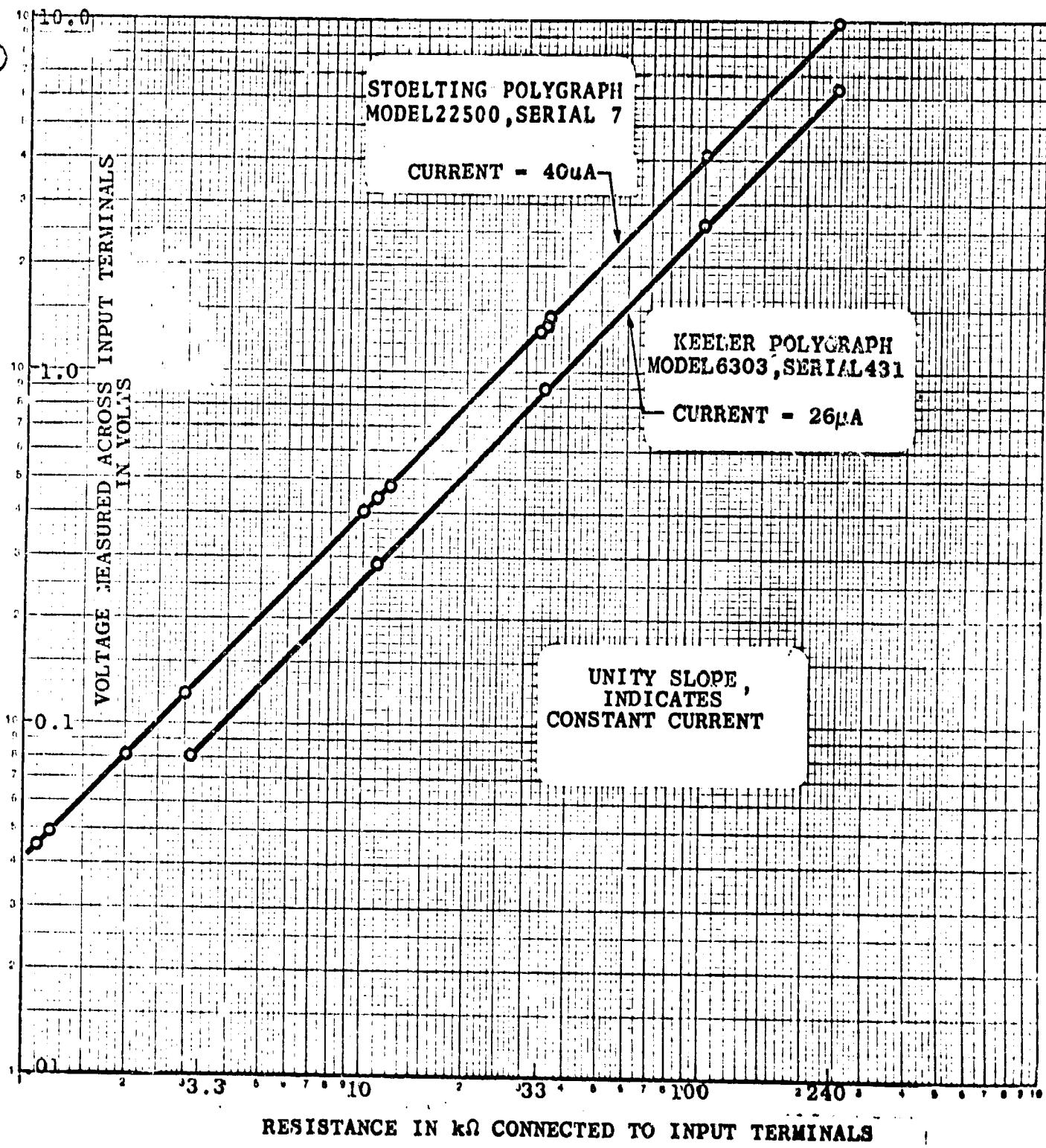


FIG. 5 DC VOLTAGE APPEARING ACROSS INPUT TERMINALS

KEELER POLYGRAPH
MODEL G303, MODEL 431

RO $100\text{k}\Omega$
SENSITIVITY Max.
ZERO Manual

DEFLECTION IN DIVISIONS (1/4")

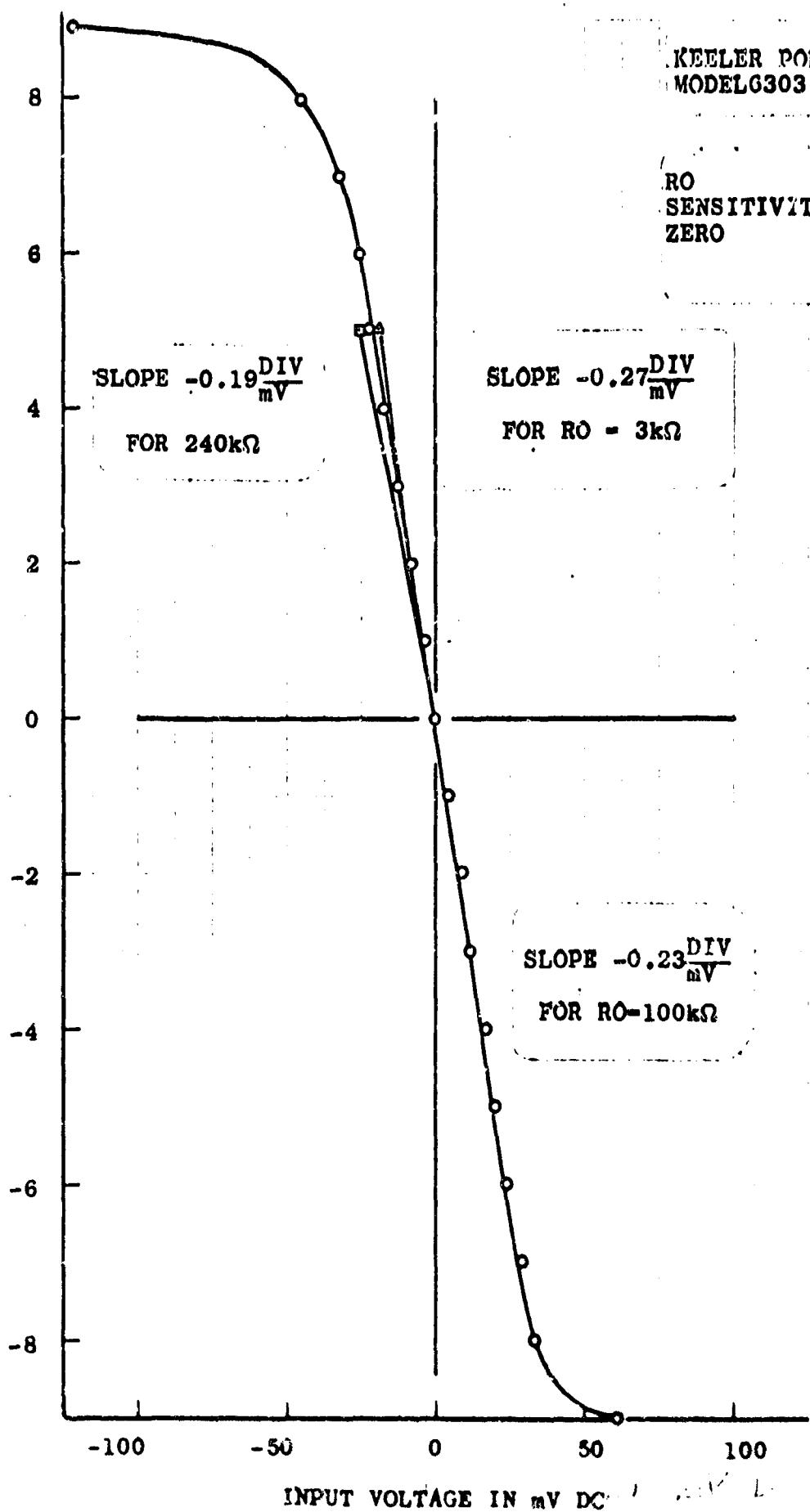


FIG. 6 OPEN CIRCUIT DEFLECTION AS A FUNCTION OF DC INPUT VOLTAGE IN SERIES WITH SUBJECT RESISTANCE, R_0 .

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6.2 Static Characteristics of Stoelting Recorder

The Stoelting recorder is sensitive to not only subject resistance and dc voltage present at the input but also ac voltages of line frequency because the input signal is chopped at the line frequency repetition rate. Care was exercised to be certain that interference from hum was not present through the use of a floating and shielded dc voltage source for the measurements described in this section.

6.2.1 Response to Change in Subject Resistance

Four graphs are shown relating deflection to change in subject resistance. Figures 7A, 7B, 7C, and 7D summarized these relationships for R_O equal to 0 Ω , 10 $k\Omega$, 100 $k\Omega$, and 240 $k\Omega$. The straight-line portions of the plots provide an indication of linearity, and slope indicates sensitivity. Figure 2D, for R_O equal to 240 $k\Omega$, shows a slight cupping shaped departure from a straight line which may be due to non-linear loading of the chopper circuit.

Sensitivity appears to be essentially independent of R_O and for this reason, pen deflection would provide a reasonable measure of change in subject resistance regardless of the value of R_O throughout the range studied.

6.2.2 DC Voltage Appearing Across Subject Resistance

The same procedures were used as described in section 6.1.2. The results are shown in Figure 5 leading to the conclusion that the dc Wheatstone bridge current is 40 μA and is independent of subject resistance.

6.2.3 Response to Applied DC Voltage

The procedure used is described under section 6.1.3. The results are summarized in the plot of Figure 8. The response is linear within $\pm 3\%$, over a range of nearly 7 divisions or approximately 50 mV.

Additional data were taken for R_O equal to 1 $k\Omega$, 10 $k\Omega$, and 240 $k\Omega$ and the results obtained agreed to within $\pm 3\%$ of that shown in Figure 8 for R_O equal to 100 $k\Omega$. The response to the applied (series) voltage appears to be reasonably independent of R_O throughout the range studied. We conclude from this that the load effect of the chopper and amplifier is essentially negligible.

DEFLECTION IN DIVISIONS (1/4")

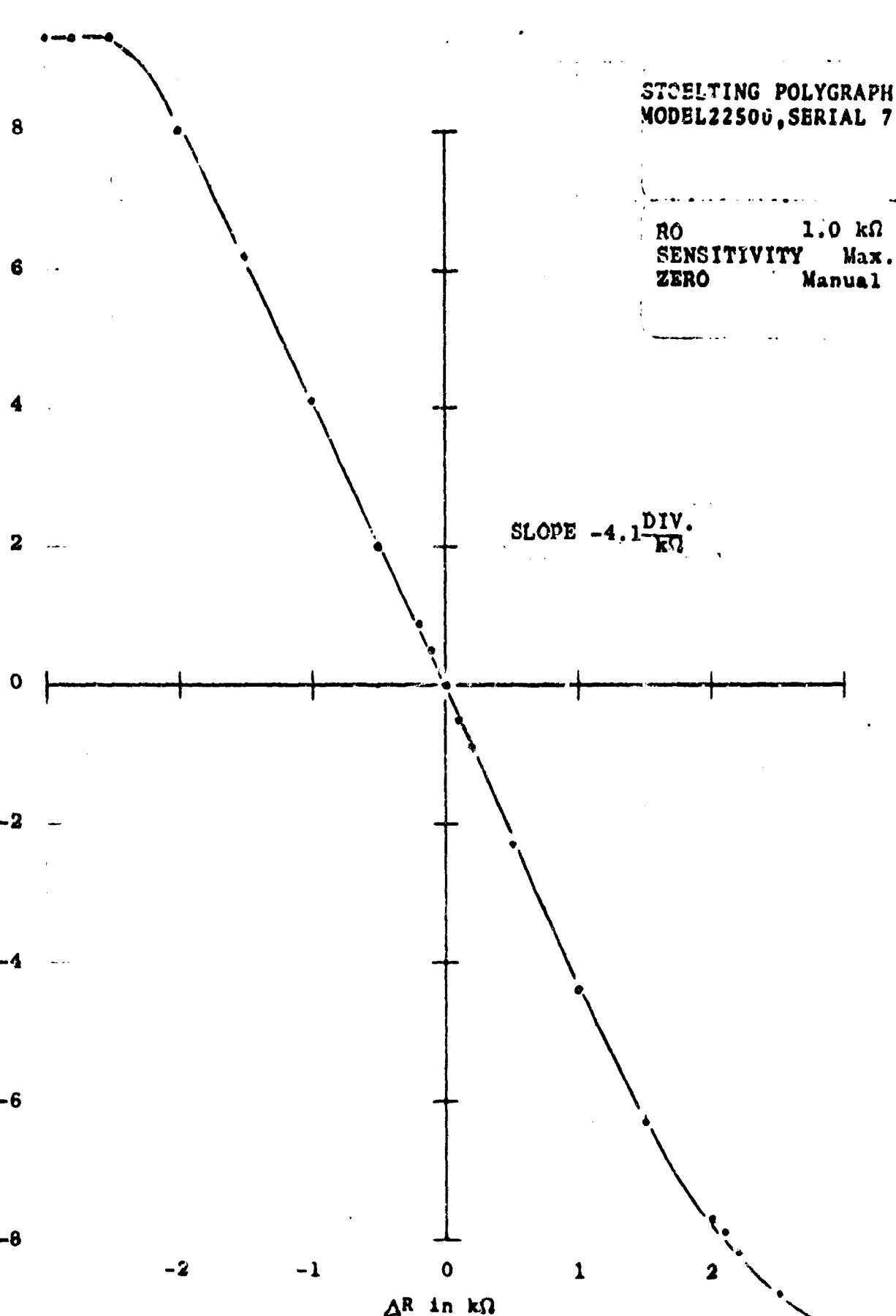


FIG. 7A PEN DEFLECTION AS A FUNCTION OF CHANGE IN "SUBJECT" RESISTANCE FOR RO = 1.0 k Ω .

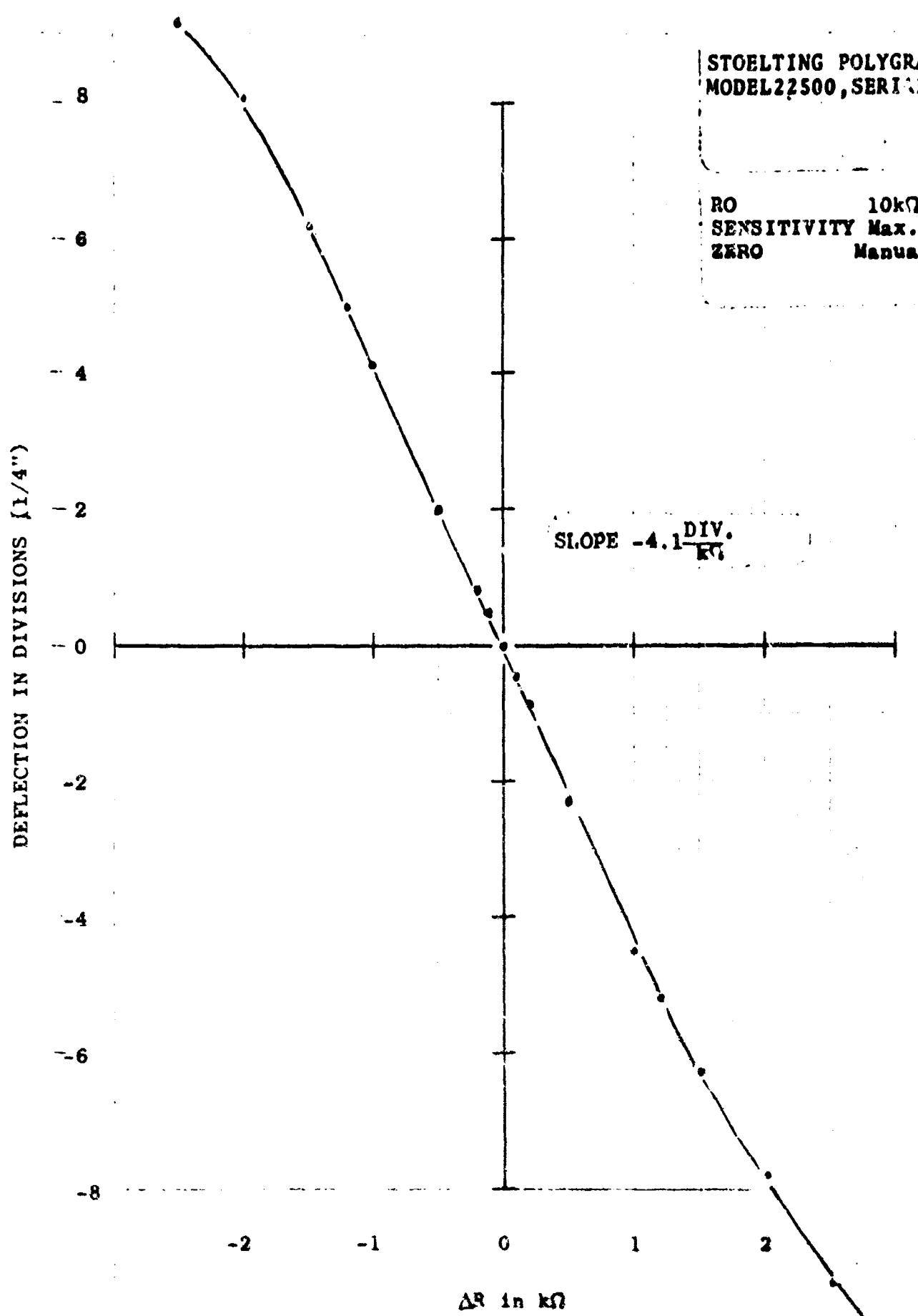


FIG. 7B PEN DEFLECTION AS A FUNCTION OF CHANGE IN "SUBJECT" RESISTANCE FOR $RO = 10\text{k}\Omega$.

STOELTING POLYGRAPH
MODEL 22500, SERIAL 7

RO 100k Ω
SENSITIVITY Max.
ZERO Manual

SLOPE -4.2 DIV.
 $\frac{k\Omega}{k\Omega}$

DEFLECTION IN DIVISIONS (1/4")

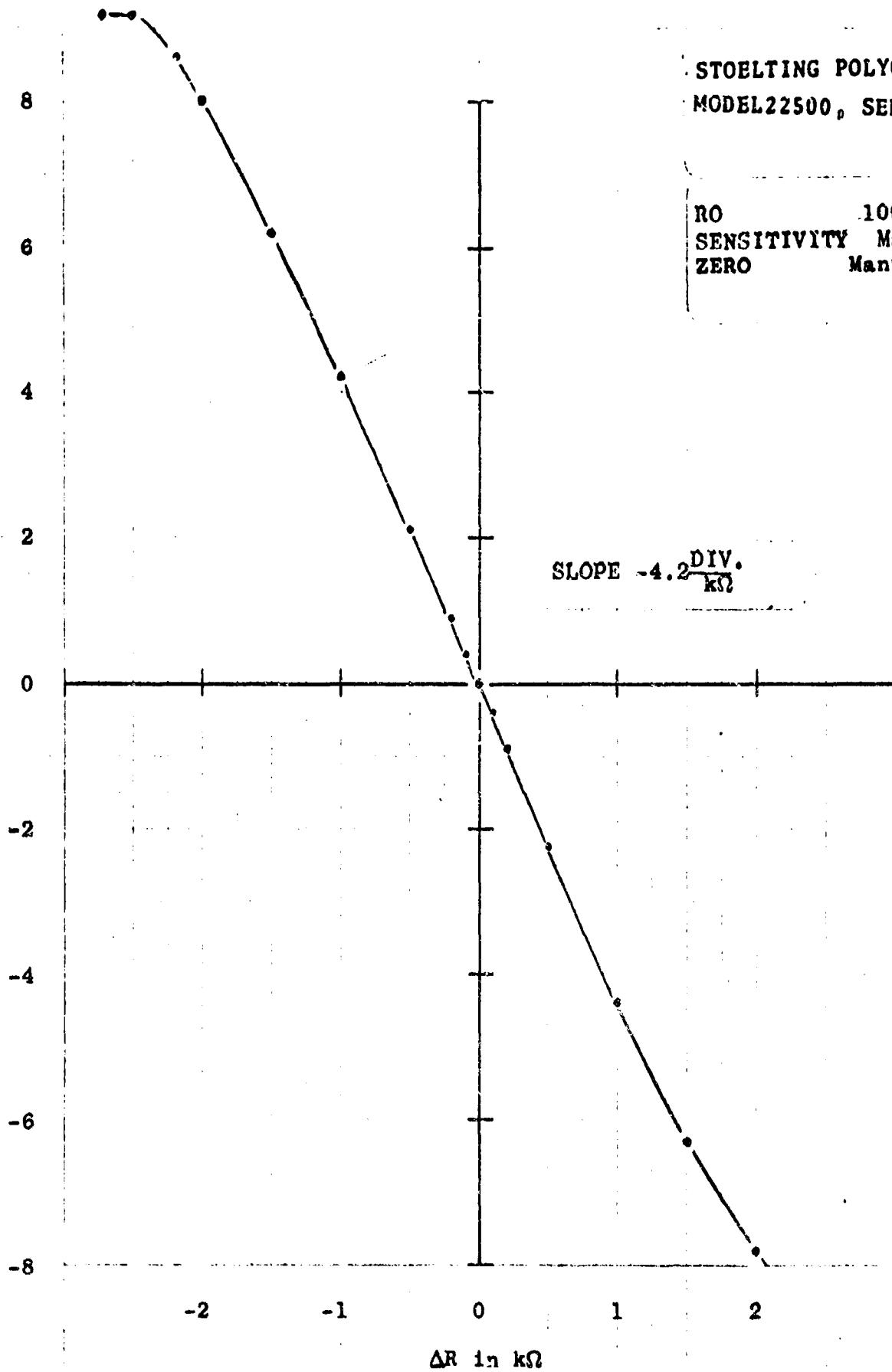


FIG. 7C PEN DEFLECTION AS A FUNCTION OF CHANGE IN "SUBJECT"
RESISTANCE FOR RO = 100k Ω .

DEFLECTION IN DIVISIONS (1/4")

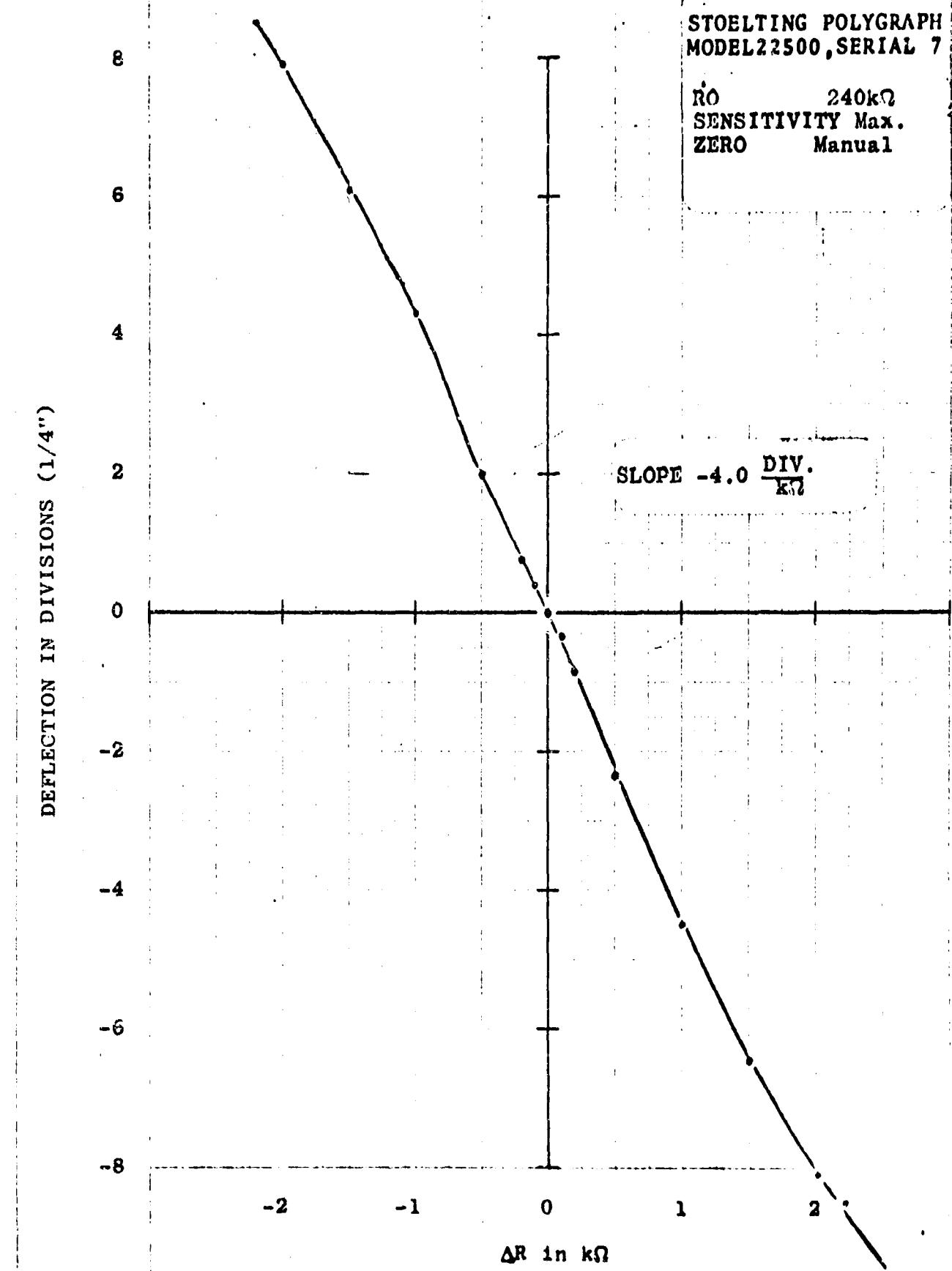


FIG. 70 PEN DEFLECTION AS A FUNCTION OF CHANGE IN "SUBJECT" RESISTANCE FOR $R_0 = 240k\Omega$.

847
STOELTING POLYGRAPH
MODEL 22500, SERIAL 7

RO 100kΩ
SENSITIVITY Max.
ZERO Manual

SLOPE -0.105 DIV.
 $\frac{\text{mV}}{\text{mV}}$

DEFLECTION IN DIVISIONS (1/4")

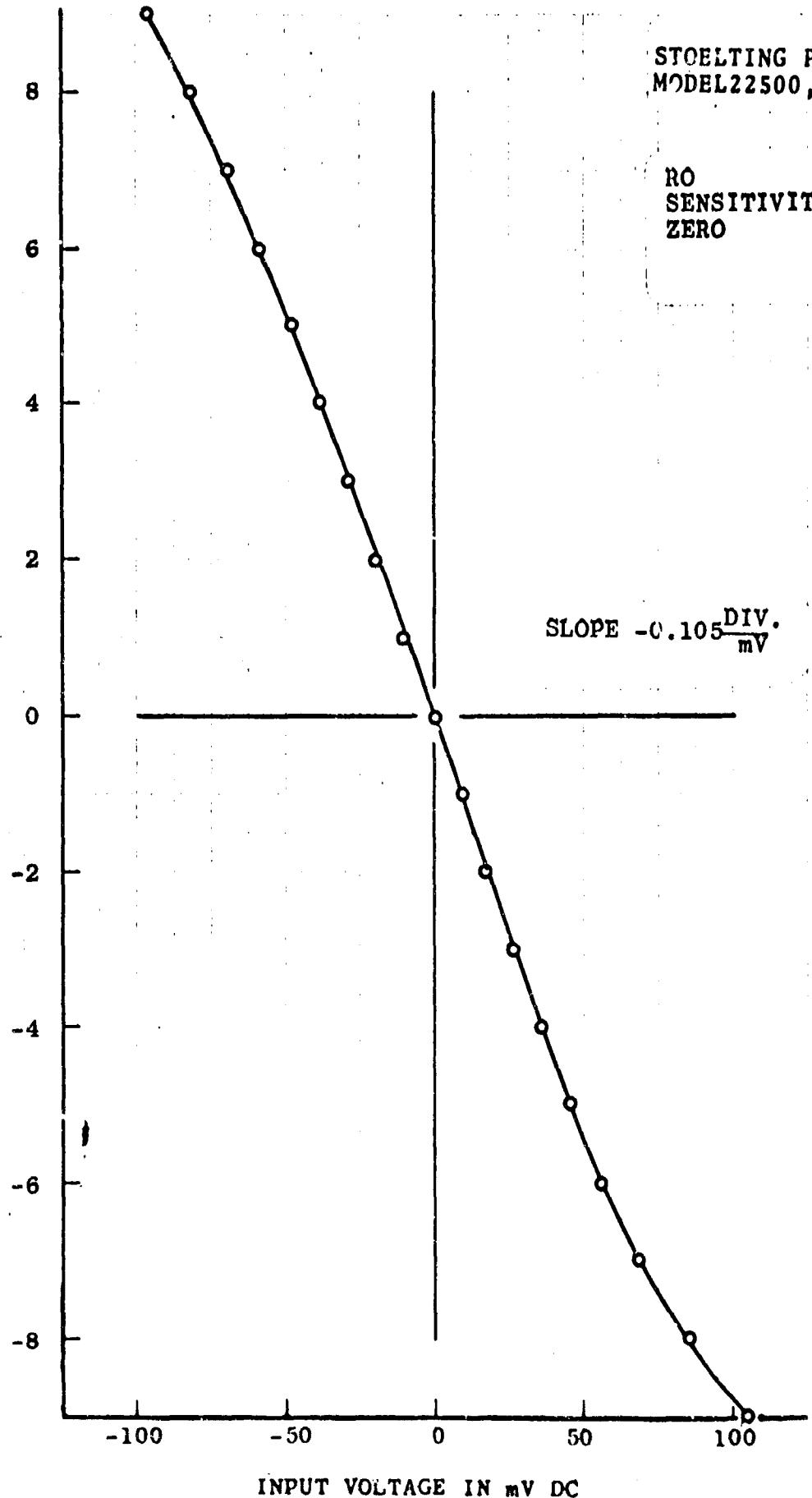


FIG. 8 PEN DEFLECTION AS A FUNCTION OF DC INPUT VOLTAGE IN SERIES WITH SUBJECT RESISTANCE, RO.

Attachment 2

VII. DYNAMIC CHARACTERISTICS

The Keeler strip-chart record is strongly influenced by pen-weight adjustment which is in the operator control domain. The influence of pen-weight, although discussed more fully in section 9.1.2, which treats the effects of operator controls, is introduced here because it cannot be ignored in the study of dynamic characteristics.

Pen weight is adjusted by means of a counterweight, a knurled nut fitted on a right-hand threaded shaft, which extends to the rear of the pen cradle. Clockwise (CW) rotation increases pen weight. The counterweight was adjusted for the least pen weight which would provide a continuous ink trace with no change in pen deflection. The resulting counterweight rotational position is considered the reference zero position. Subsequent heavier pen weights were required, depending upon the magnitude and manner of pen deflection, and are specified in terms of the number of CW turns of the counterweight with respect to the zero position defined above.

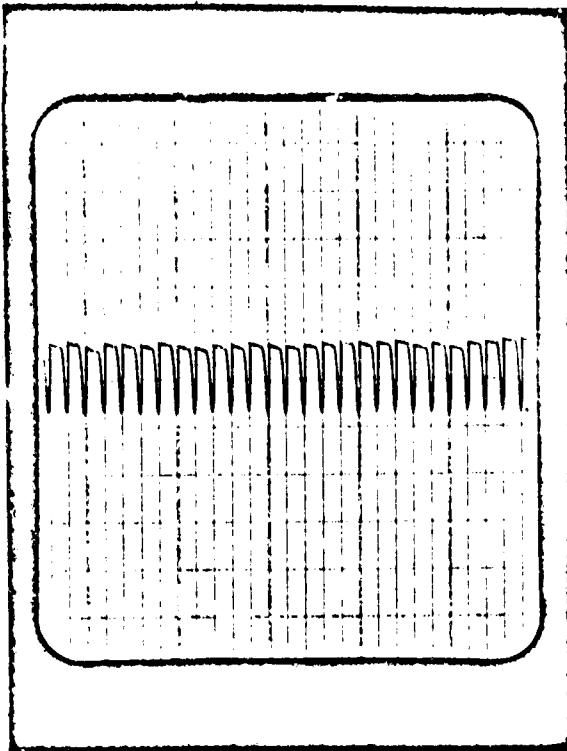
7.1 Chart Speed

Chart speed is indicated in Figure 9 for both recorders. A timing pulse having a one-second repetition rate derived from WWV transmissions was applied to the input and the chart drive of each recorder allowed to run for several minutes. Only a short portion of the time record is shown. The heavy vertical lines in the strip chart represent five-second intervals. The timing pulses fell on the vertical lines with some slight variation during several minute intervals. A close examination of Figure 9 shows a short-term variation in the order of 5% for the Stoelting recorder and less than half of this for the Keeler.

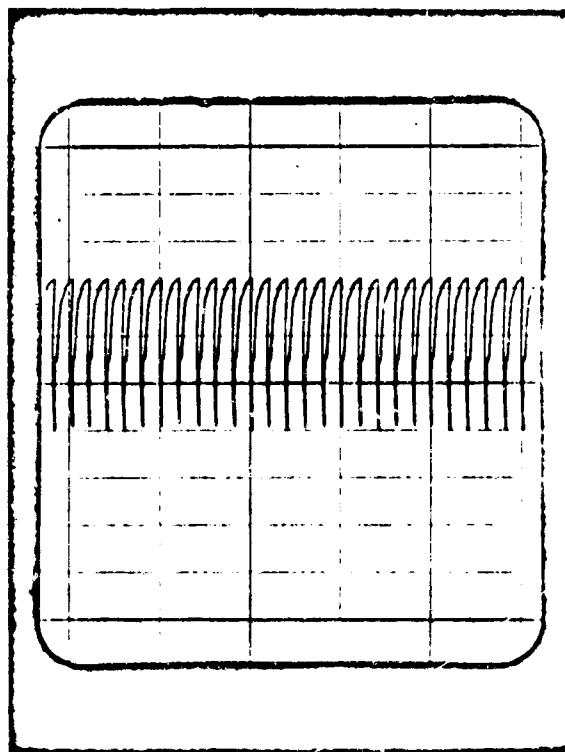
7.2 Mechanical Oscillation

The natural frequency of oscillation of the galvanometer movement with the recorder turned on was determined by mechanically deflecting the pen nearly full scale and releasing it. The ink traces are shown in Figure 10. The natural frequency of oscillation was scaled and, knowing chart speed, is expressed as approximately 1.5 Hz for the Keeler recorder and 5.0 Hz for the Stoelting. This information proved to be of value in a better understanding of the somewhat complex frequency response of the systems described below.

7-1966
9



KEELER POLYGRAPH
MODEL 6303, SERIAL 431



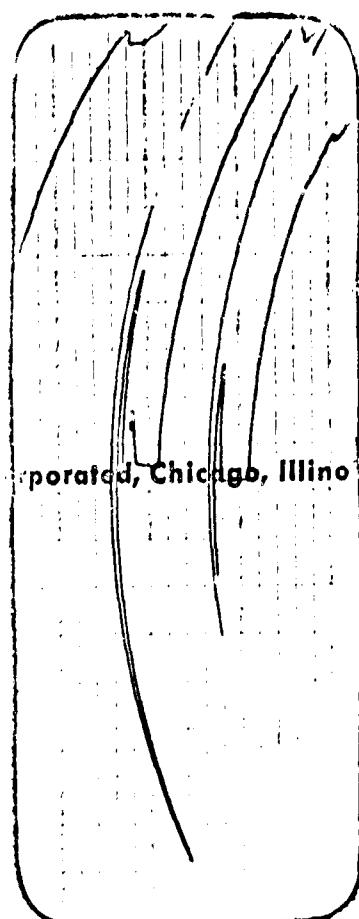
STOELTING POLYGRAPH
MODEL 22500, SERIAL 7

FIG. 9 CHART SPEED INDICATED BY ONE-SECOND TIMING PULSES
FROM WWW

KEELER POLYGRAPH
MODEL G303, SERIAL 431

TOP 10

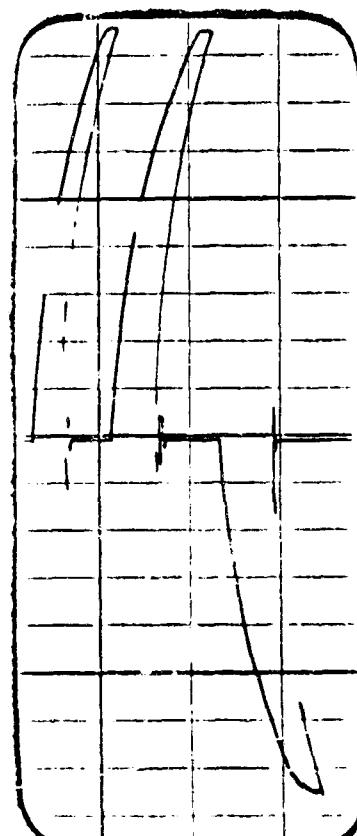
10



porated, Chicago, Illinois

OSCILLATION
1.5 HZ
RATE

STOELTING POLYGRAPH
MODEL 22500, SERIAL 7



OSCILLATION
5 HZ
RATE

FIG. 10 MECHANICAL OSCILLATIONS

7.3 Response to Sine-Wave Input Voltage

A sine-wave voltage was applied across a ten-ohm resistor which was connected in series with R_O, a 5-k Ω resistor. The operating conditions were as follows:

RC	5 k Ω
ZERO	manual
SENSITIVITY	maximum
CENTURING	zero

The 1-Hz sine-wave voltage was set to an amplitude sufficient to produce approximately ±0.15 division peak-to-peak deflection. The voltage amplitude remained fixed as the frequency was increased to over 12 Hz in a period of one minute. The frequency sweep produced the two charts shown in Figure 11. The upper chart reveals that the Keeler recorder is extremely sensitive to frequencies in the order of 1.7 Hz which has been shown in section 7.2 to be the natural frequency of oscillation of the galvanometer. The increase in sensitivity is a factor of more than 50 from 1 Hz and 1.7 Hz and the observed behavior is characteristic of a system having a pass-band filter. The effect of this "filter" characteristic is to greatly enhance the systems response to those frequency components of the input signal falling within the pass band and especially those components having frequencies close to the center of the pass band.

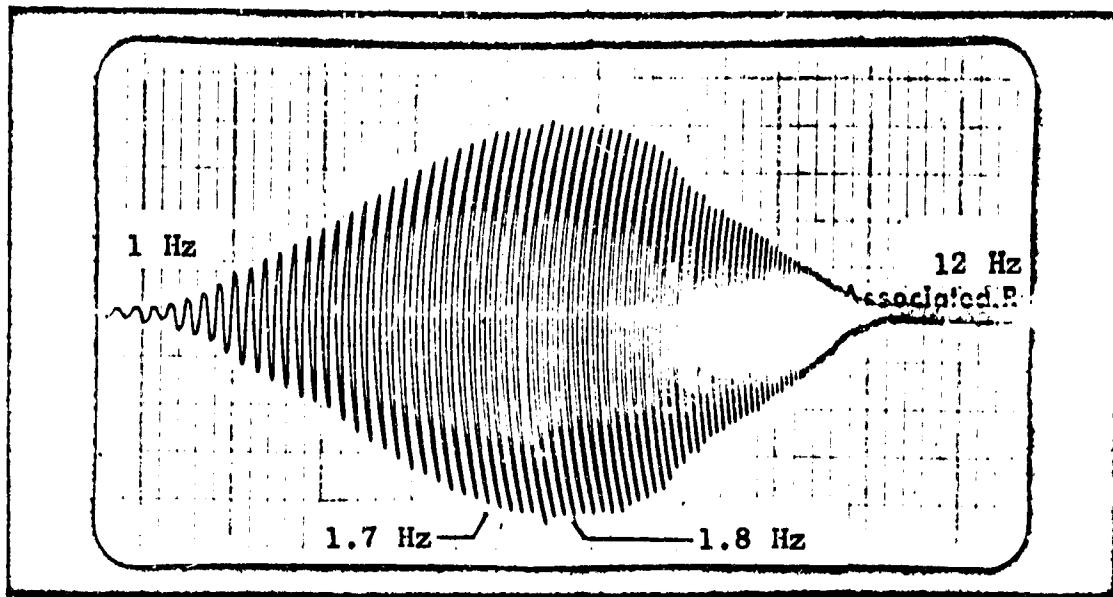
The frequency sweep plot also shows that the system continues to be responsive to frequencies through 12 Hz and higher.

In strong contrast, the Stoelting recorder exhibits a gradual decrease in sensitivity in the region from 1 Hz to 12 Hz, as shown in the lower chart of Figure 11.

The responses of the recorders were examined in greater detail in the frequency spectrum from fractional values of Hz to approximately 10 Hz which covers essentially the entire spectrum of significant response.

Several graphs are shown in Figure 12 for the Keeler recorder. The upper plot gives the relationship between pen deflection and frequency for a constant voltage applied to the ten-ohm resistor. The lowest frequency, 0.02 Hz was chosen to show that the response was flat in that region and the amplitude of the input signal was adjusted to give a nominal 5 division swing above and below the center line (i.e. 10 divisions from peak to peak). The plot shows a pronounced peaking at 1.4 Hz where the pen swing was ±6.2 divisions caused by galvanometer natural frequency of oscillation.

44-1117
//
KEELER POLYGRAPH
MODEL 6303, SERIAL 431



STOELTING POLYGRAPH
MODEL 22500, SERIAL 7

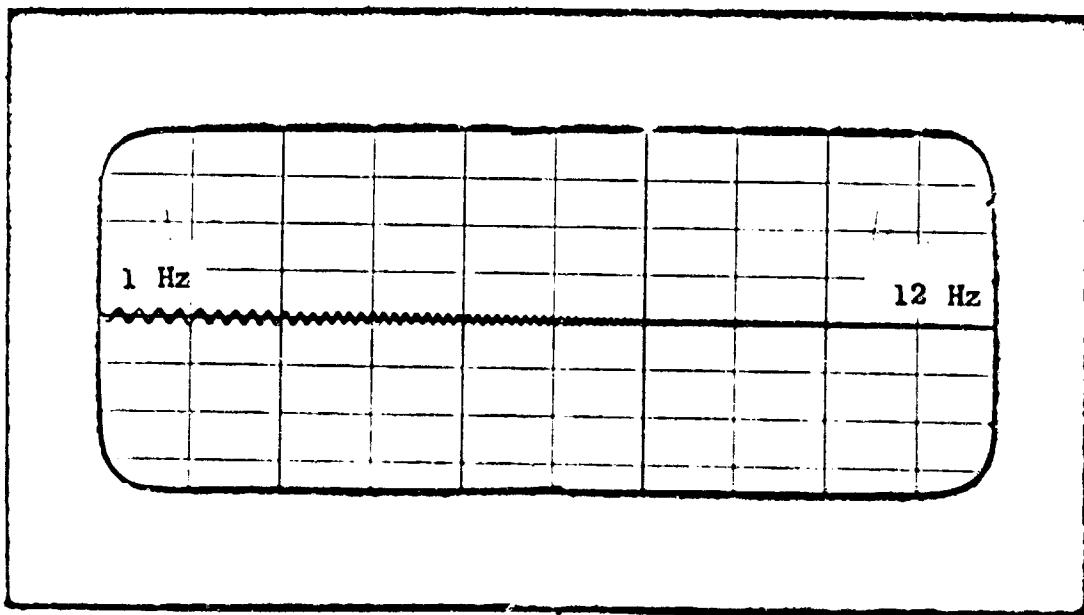
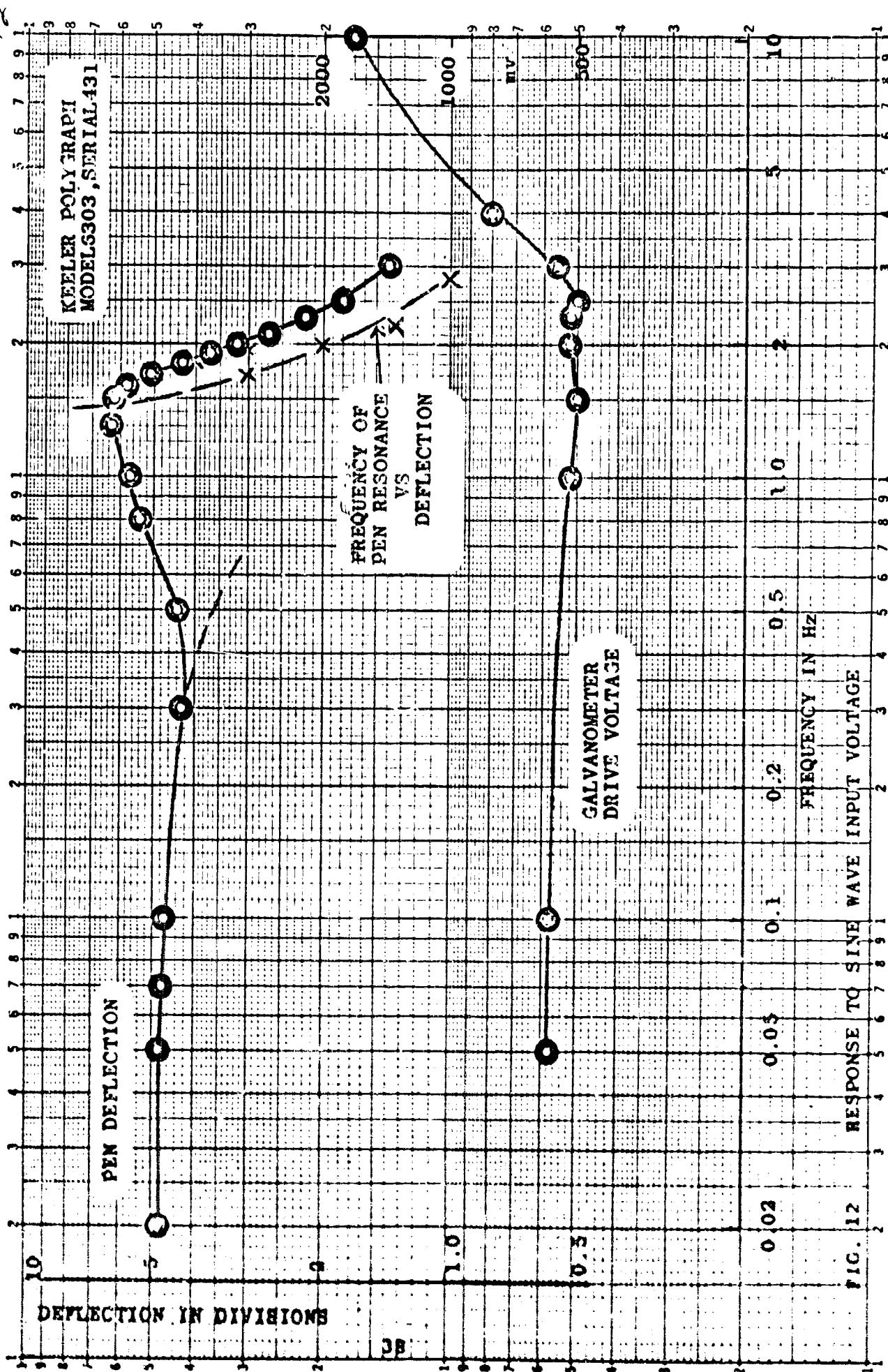
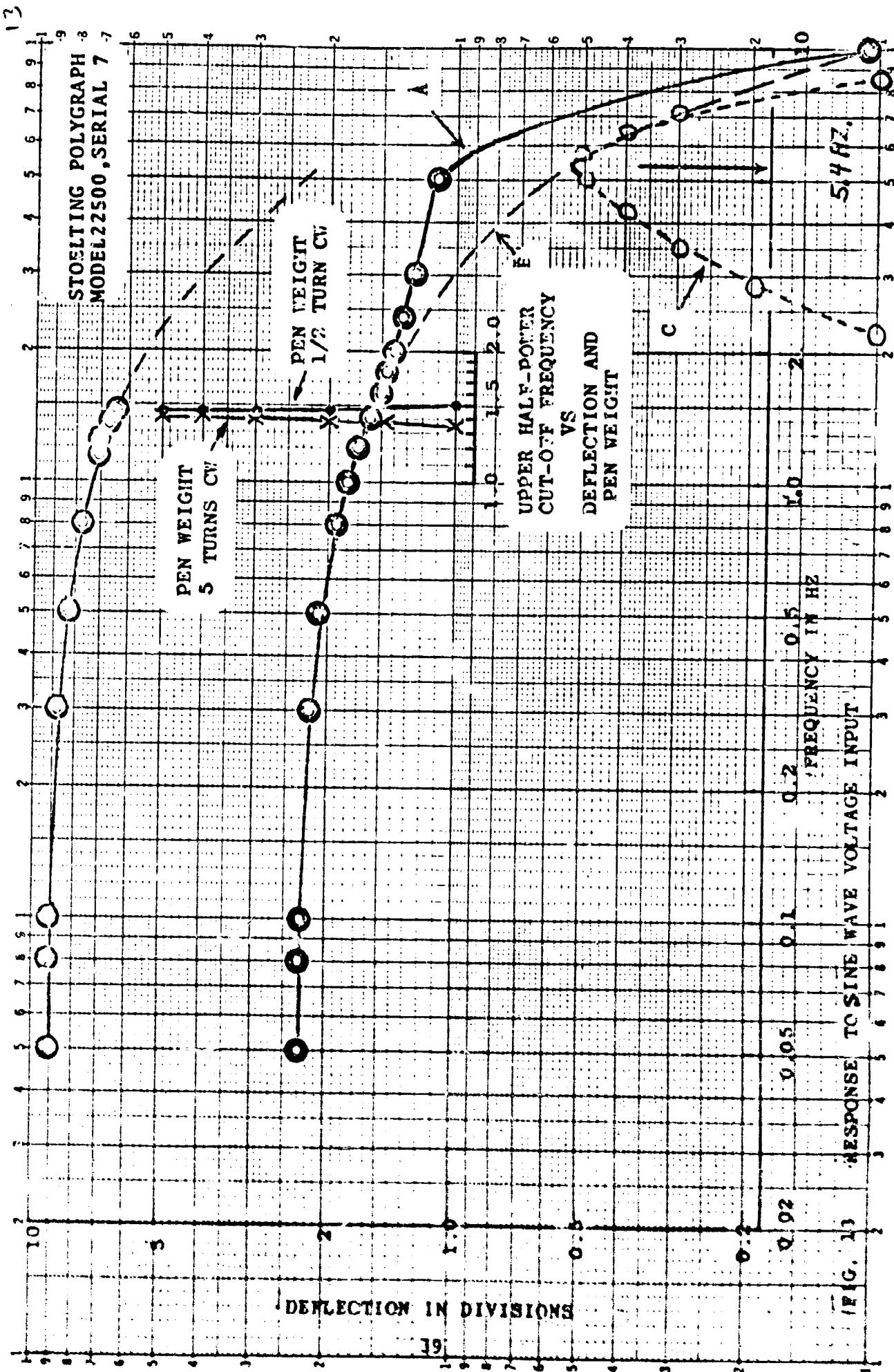


FIG. 11 INPUT, CONSTANT-VOLTAGE FREQUENCY SWEEP FROM 1 Hz to 12 Hz.

K-E LOGARITHMIC 467520
2 X 3 CYCLES MADE IN U.S.A.
KEUFFEL & ESSER CO.



LOGARITHMIC 467320
2 X CIRCLE.
REDFIELD & ESSON CO.



Attachment 2

By reducing the magnitude of the input voltage it was shown that the natural frequency of oscillation increases. This is indicated in Figure 12 by the curve labeled "Pen Resonance vs Deflection." There is reasonable agreement between the resonance point of 1.7 Hz in Figure 11 for ± 4 divisions swing and the interpolated value of approximately 1.6 Hz in Figure 12. The 2 to 1 change in resonant frequency associated with a change from ± 1 to ± 8 division swing, although clearly shown here, would defeat any attempt to analyze a varying input signal in this frequency region.

The lower curve of Figure 12 indicates the galvanometer drive voltage (scale to the right). Notice that there is no corresponding significant hump in the drive voltage plot thus substantiating the conclusion that pen resonance is of mechanical origin.

The rapidly increasing drive voltage above 2 Hz is insufficient to overcome pen inertia and therefore, the plot of pen deflection rapidly decrease. The response is extended, however, to higher frequencies. The response at 12 Hz shown in Figure 11 may appear questionably excessive. If however, the curve of "Frequency of Pen Resonance vs Deflection" is extrapolated, it seems reasonable that pen resonance effects may be present for pen excursions in the order of ± 0.4 divisions at 12 Hz and may well affect the observations in Figure 11.

A somewhat similar measurement procedure was followed in examination of the behavior of the Stoelting recorder. The results are given in Figure 13. Response of pen deflection to sine-wave voltage input was plotted for ± 9 division pen swing and ± 2.3 division pen swing. The two plots are similar in shape through 1.5 Hz which is the frequency* at which the deflection is 70% of the deflection measured well within the flat response region of the pass band (i.e. below 0.1 Hz).

The upper half-power frequency is slightly dependent upon pen weight and deflection. The relationship is shown by the two plots labeled "Upper half-power cut-off Frequency vs Deflection and Pen Weight." These plots show that these two factors are not particularly important in influencing the system's response.

* This frequency corresponds to the half-power frequency which is commonly used to define the limit of a pass band. In this instance it is the upper half-power frequency.

Attachment. 2

The lower plot in Figure 13 labeled A is extended to 10 Hz. It shows a hump at 5 Hz and sharply decreasing response through 10 Hz. If the irregularity in A were ignored the curve would follow the dashed lines labeled B. The effect causing the irregularity in A may be estimated by plotting the difference. This was done and the resulting points and curve are shown and labeled C. Curve C has the appearance expected of pen resonance effects with a center frequency in excellent agreement with the natural frequency of oscillation of the pen derived from Figure 10. The effect of pen resonance is shown here as to extend the upper pass band somewhat. The effect does not produce any marked discontinuities in the pass band.

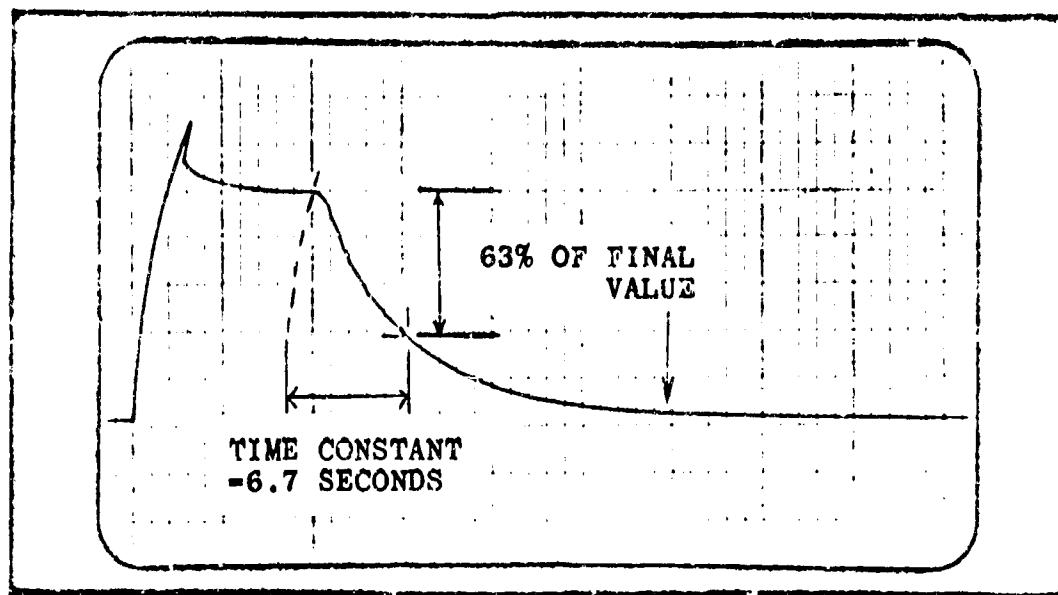
7.4 Time Constant of ZERO-auto Mode

The ZERO-auto mode of operation introduces a restoring force to the pen which constantly causes the pen to seek the zero center position. The restoring force adds algebraically to the deflection force produced by the input signal, and decays in a simple exponential manner with time. The exponential decay characteristic is shown in Figure 14 for the Keeler recorder and Figure 15 for the Stoelting. For each chart the initial conditions were --

RO	101 k Ω
ΔR	1 k Ω
ZERO	manual
SENSITIVITY	adjusted to produce 5 division change with ΔR 1 k Ω .
CENTERING	zero center
PEN WEIGHT	set to minimum value for 5 division step deflection

A step change of ΔR was introduced and, as shown, the pen deflection was allowed to reach a stable value. This required over 5 seconds for the Keeler and 2 seconds for Stoelting under these conditions. The zero mode was changed to automatic and the time required for the pen to return to zero deflection observed. The most convenient form for expression of the rate of decay is the time* required to reach 63% of the full change in deflection. Referring to Figure 14, the downward and upward estimated rates of return to zero deflection are 6.7 and 6.4 seconds for the Keeler recorder. The small difference between these two estimates of time constant, although measurable, is not considered significant. Figure 15 shows the corresponding estimated time constants for the Stoelting recorder to be 1.9 seconds in each direction.

* This time is numerically equal the time constant which is commonly used to described exponential rate of decay.



KEELER POLYGRAPH
MODEL 6303, SERIAL 431

PEN WEIGHT
2 TURNS CW

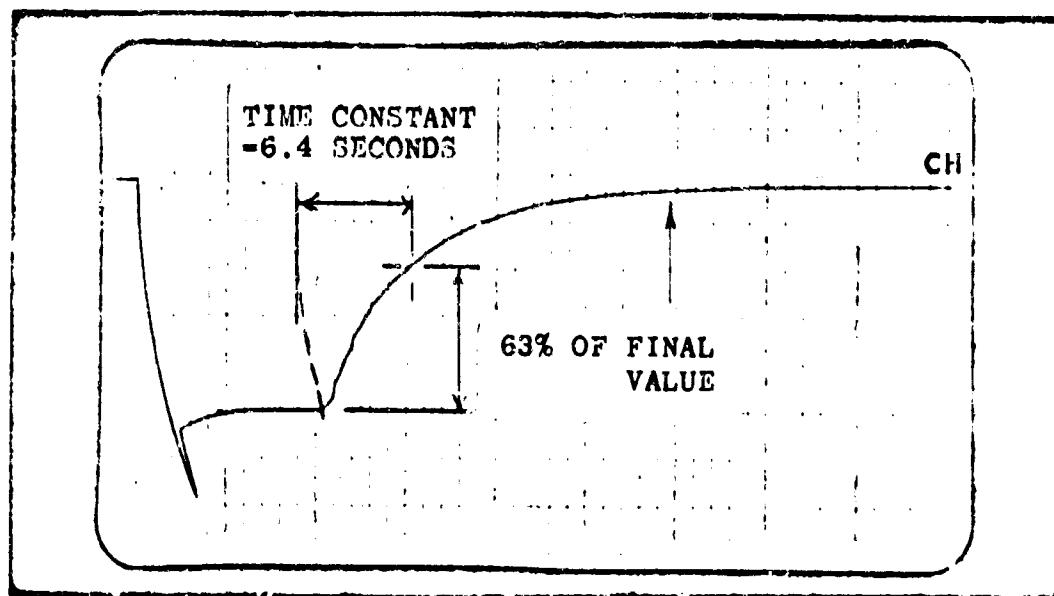
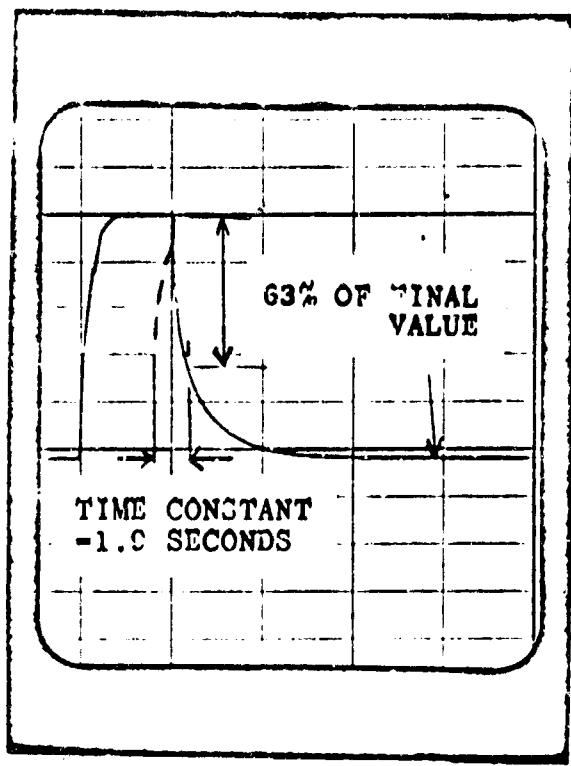


FIG.14 RESPONSE TO STEP CHANGE IN INPUT FOR AUTO-ZERO



STOELTING POLYGRAPH
MODEL 22500, SERIAL 7

PEN WEIGHT
2 1/2 TURNS CW

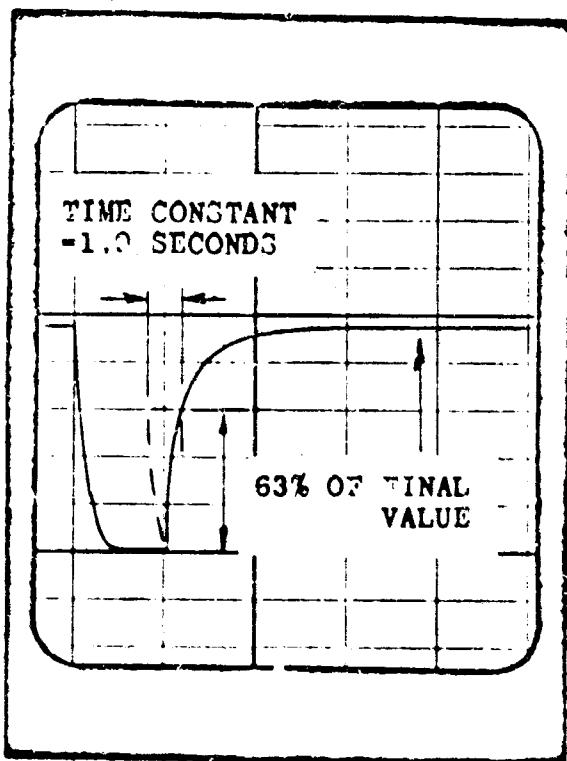


FIG. 15 RESPONSE TO STEP CHANGE IN INPUT FOR AUTO-ZERO

Attachment 2

The above described procedures provide a useful means for establishing the value of the principal parameter by which to quantify the auto-zero mode of operation. As a result of this measurement procedure we may establish whether or not two recorders are alike or are different. For the present comparison, the time constants are sufficiently different to conclude that, in general, quite different responses would be expected for the same input signal. The extent of this difference cannot be readily determined because the effect of time constant above cannot be isolated from all the other effects which are known to be present. It is instructive however, to examine and compose examples of chart records for manual-zero mode and an auto-zero mode of operation. Such records are shown in Figures 16A, 16B, and 17. The input subject resistance was varied by the automatic switching equipment described in Appendix II. Comparison of manual-zero and auto-zero modes were made for three dwell times, 0.5, 1.0, and 2.0 seconds. Pen weight was adjusted to the lightest setting to produce a full ink trace for that deflection so as to minimize pen drag effects. (This does not eliminate pen drag effects, as will be shown later.)

Two Figures, 16A and 16B, are shown for the Keeler recorder because it exhibits two modes of response depending mainly upon the amplitude of pen deflection. For small deflections the response is characteristically overdamped and this response mode is represented in Figure 16A. For large deflections the response is underdamped, as represented in Figure 16B.

On the other hand, the Stoelting recorder is characteristically overdamped throughout the full scale and it is represented in Figure 17.

It would appear from these figures that the effect of the auto-zero mode of operation produces little change if the dwell time is small such as 0.5 seconds, compared to the auto-zero time constant, and in addition, where the running average value of the deflection lies close to zero (as is the case for these figures). Otherwise, and in general, the auto-zero feature has a pronounced effect on the character of the record which can only mask the nature of the input signal.

VIII. DRIFT CHARACTERISTICS

A procedure was followed for monitoring calibration and drift. Sixteen sets of measurements were made in a period covering one month. At the end of the day during which the

KEELELR POLYGRAPH
MODEL 6303, SERIAL 431

PEN COUNTERWEIGHT
ADJUSTED TO 2 G.

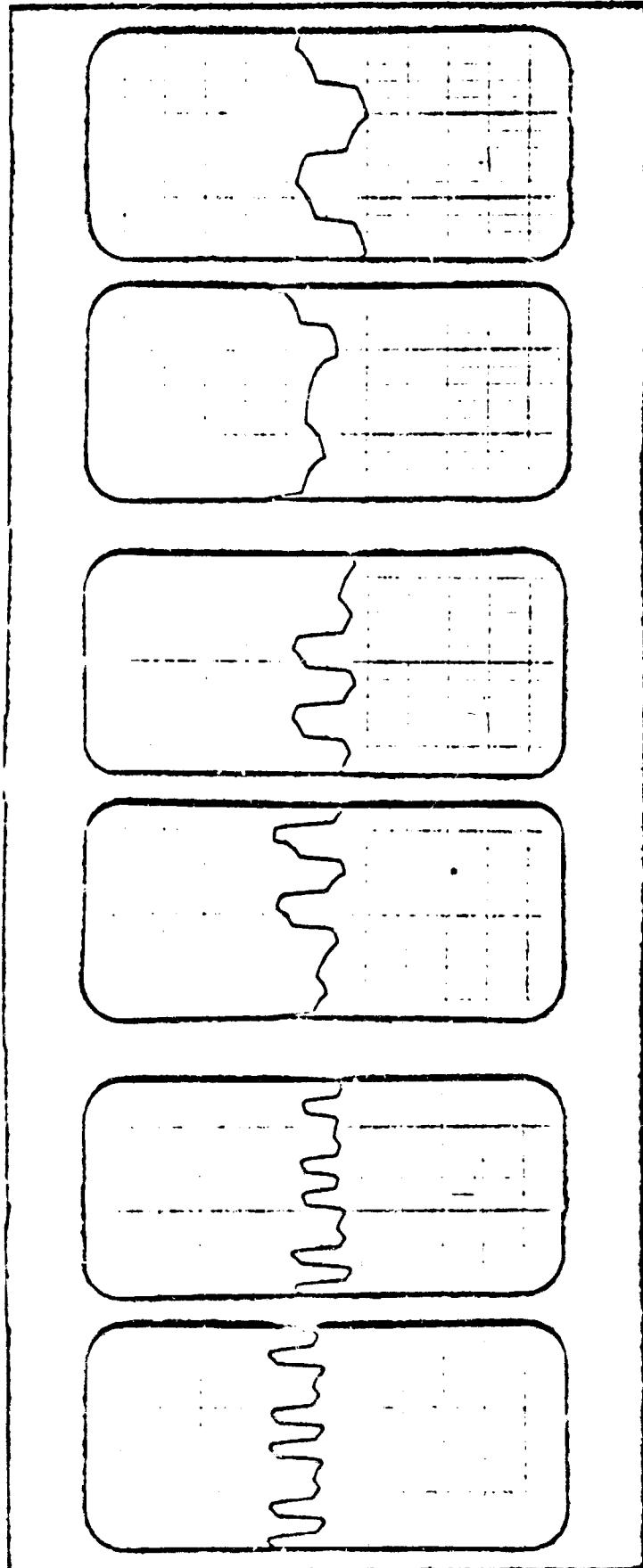
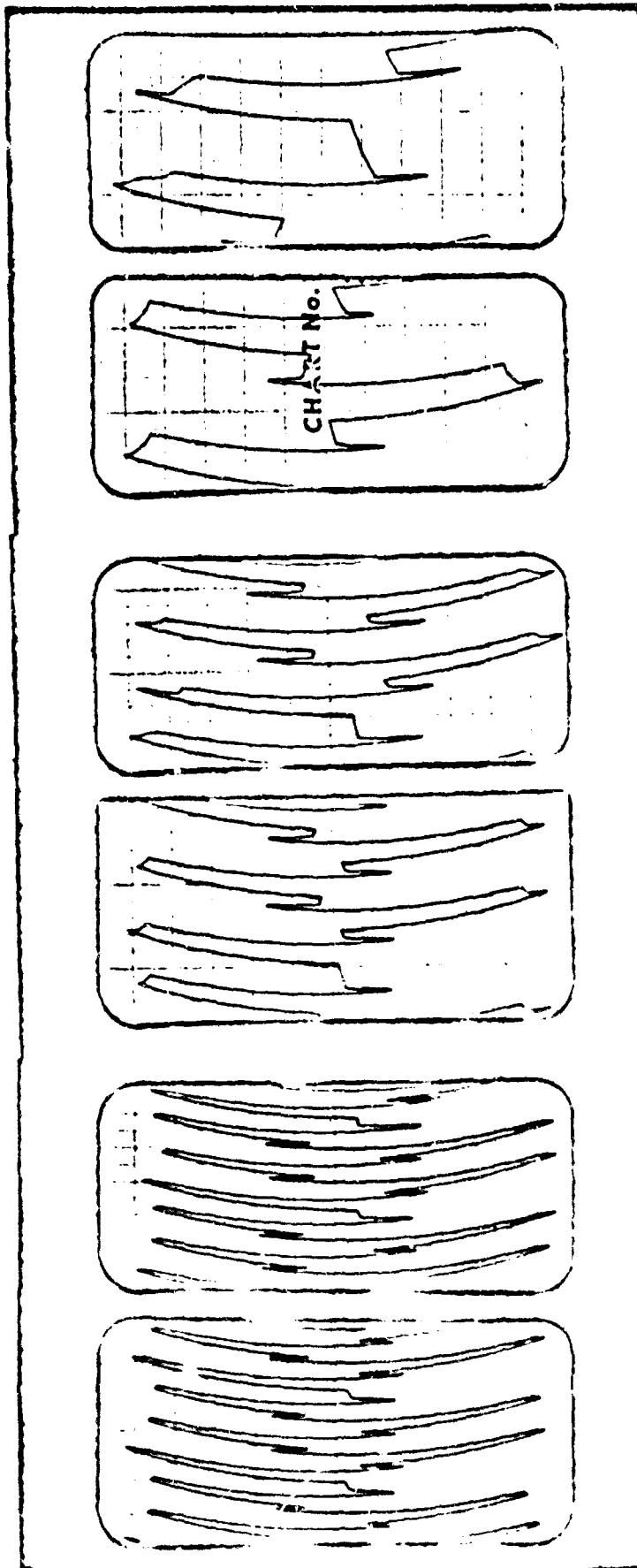


FIG. 16A CHART RECORDS FOR STEP CHANGES IN RESISTANCE SHOWING COMPARISON BETWEEN
MANUAL-ZERO AND AUTOMATIC-ZERO OPERATION FOR APPROXIMATELY $\pm 1/2$ DIVISION
DEFLECTIONS.

KEELEER POLYGRAPH
MODEL 6303, SERIAL 431

PEN COUNTERWEIGHT
ADJUSTED TO 2 CW



MANUAL	ZERO	AUTO	MANUAL	ZERO	AUTO
			DWELL TIME		
			1.0 SECONDS		2.0 SECONDS

FIG. 16B CHART RECORDS FOR STEP CHANGES IN RESISTANCE SHOWING COMPARISON BETWEEN
MANUAL-ZERO AND AUTOMATIC-ZERO OPERATION FOR APPROXIMATELY ± 4 DIVISION
DEFLECTIONS

STOELETTING POLYGRAPH
MODEL 22500, SERIAL 7

PEN COUNTERWEIGHT
ADJUSTED TO 2-1/2G.

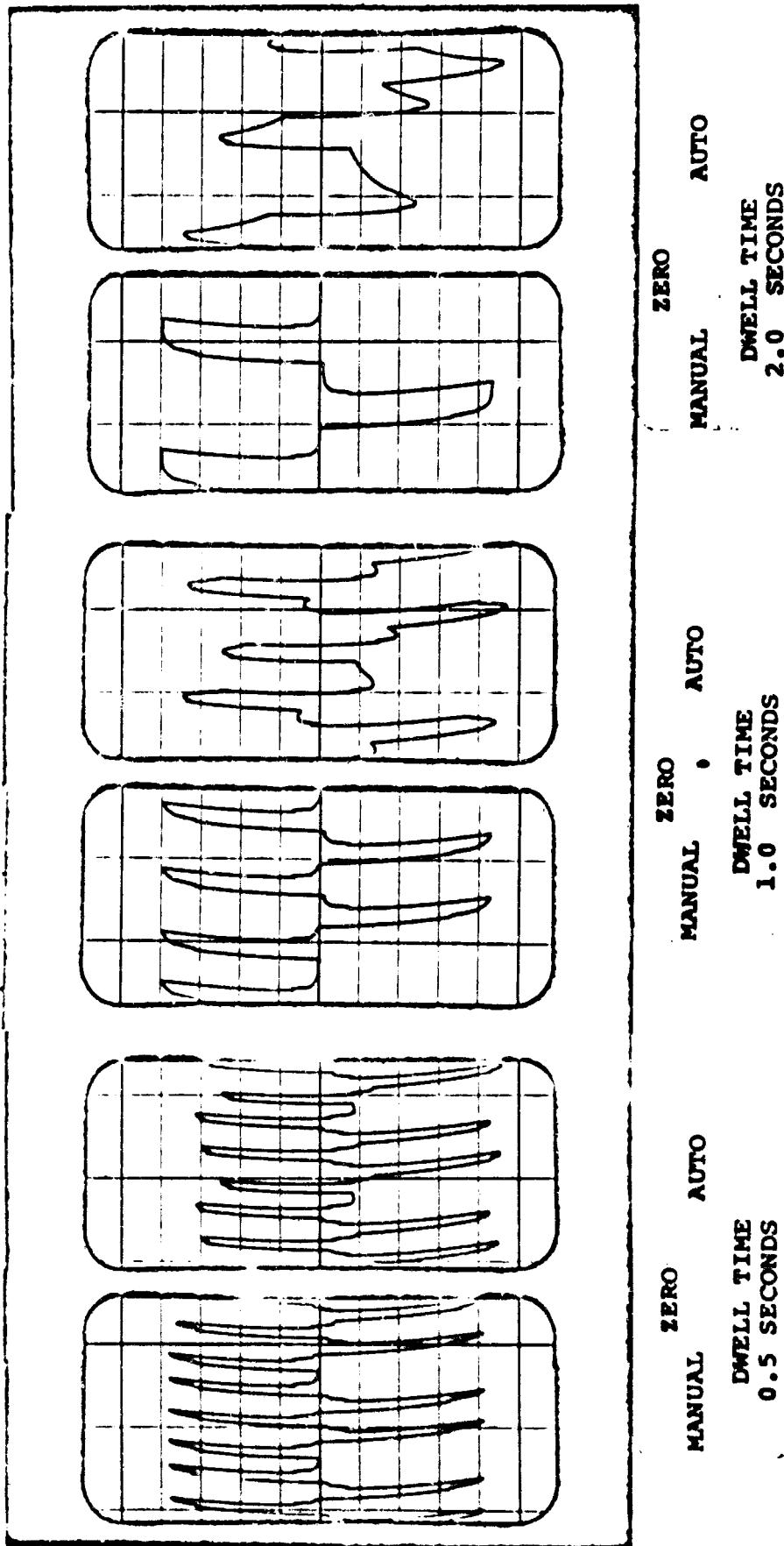


FIG. 17

CHART RECORDS FOR STEP CHANGES IN RESISTANCE SHOWING COMPARISON BETWEEN
MANUAL-ZERO AND AUTOMATIC-ZERO OPERATION FOR APPROXIMATELY ± 4 DIVISION
DEFLECTIONS.

recorders were used they were adjusted to preselected conditions, described in the next paragraph, and then turned off. The following morning a set of measurements was recorded during the first half hour. These measurements provided information on stability of calibration and on drift during first half hour of operation.

The adjustments made the previous evening, after the equipment had run all day, were as follows:

RO	51 k Ω (Keeler only)
ΔR	1.5 k Ω (Keeler only)
ZERO	manual
SENSITIVITY	maximum (because this setting is highly repeatable)
CENTERING	zero center

The same adjustments were made for the Stoelting recorder, except,

RO	101 k Ω (Stoelting only)
ΔR	1 k Ω (Stoelting only)

On the following morning the pen deflection was noted before turning the recorder on so as to measure mechanical balance. Afterwards the recorders were turned on and following warm-up periods of 3, 10 and 30 minutes, pen deflection records were made cycling the step values of subject resistance given above (as described earlier and in Appendix II).

Analysis of the 16 sets of pen deflection data reveals that the mechanical balance was quite stable for both recorders, repeating within ± 0.1 division.

The electrical balance, indicated by pen deflection for RO, changed during the first thirty minutes of operation. The change is indicated by first normalizing the entire set of measurements to the 30-minute center-value pen deflection reading to zero. The resulting average values for the three time points are shown in Table II.

Table II
Relative Drift of the Center Value

Elapsed Time After Turning On	KEELER	STOELTING
	Average Deflection of the 16 Daily Measurements	
3 minutes	0.2 divisions	2.5 divisions
10	0.1	1.1
30	0.0	0.0

11

Attachment 2

The Keeler recorder stabilizes relatively rapidly and shows little drift after the first few minutes of operation. The Stoelting shows relatively large drift, and from these measurements one would suspect that the center value does not reach a stable value even after 30 minutes of warm-up. (A second set of measurements covering eight hours of operation was made to check this and is reported later in this section.)

Finally, the 16 sets of measurements were analyzed to determine the stability of sensitivity in terms of deflection associated with ΔR . For the Keeler recorder, the deflections were symmetrical about the center line and the average equal to +3.1 and -3.1 divisions with an average of 6.3 divisions peak-to-peak. The estimated standard deviation of the peak-to-peak value is 1.10 which expressed in terms of relative error (or coefficient of variation which is equal to the standard deviation divided by the mean) is 0.016 or 1.6%.

For the Stoelting recorder the deflection average was +4.2 and -4.6 with the peak-to-peak average of 8.8. The associated standard deviation was estimated to be 0.16 and the relative error, 1.8%.

These data indicate that stability of mechanical balance and sensitivity is very satisfactory. The drift of the zero-center of the Stoelting appears excessive. This parameter was examined further for both recorders.

Each recorder was adjusted as follows:

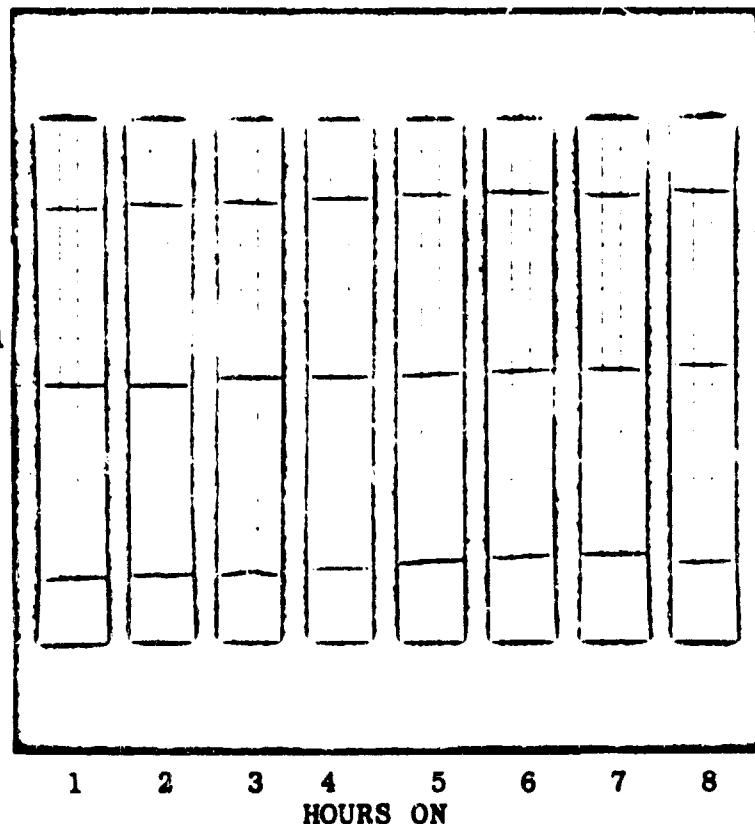
RO	101 k Ω
ΔR	1 k Ω
ZERO	manual
SENSITIVITY	set so that RO: ΔR produced +4 division deflection
CENTERING	zero

Line voltage was held at 115 volts (as usual). The SENSITIVITY and CENTERING settings were readjusted after a warm-up period of one hour. Parallel pen traces were made for RO- ΔR , RO and RO+ ΔR values of subject resistance at this time and repeated every hour through 8 hours without making any changes in operating conditions. The results are shown in Figure 18.

The zero-center deflection of the Keeler recorder gradually shifted upscale 0.4 divisions. The sensitivity gradually decreased until by the 7th hour the change was 0.2 divisions or 5%. By the 8th hour the sensitivity had returned to the original value. These variations are of approximately the same magnitude as those associated with

115V

KEELER POLYGRAPH
MODEL 6303, SERIAL 431



STOELTING POLYGRAPH
MODEL 22500, SERIAL 7

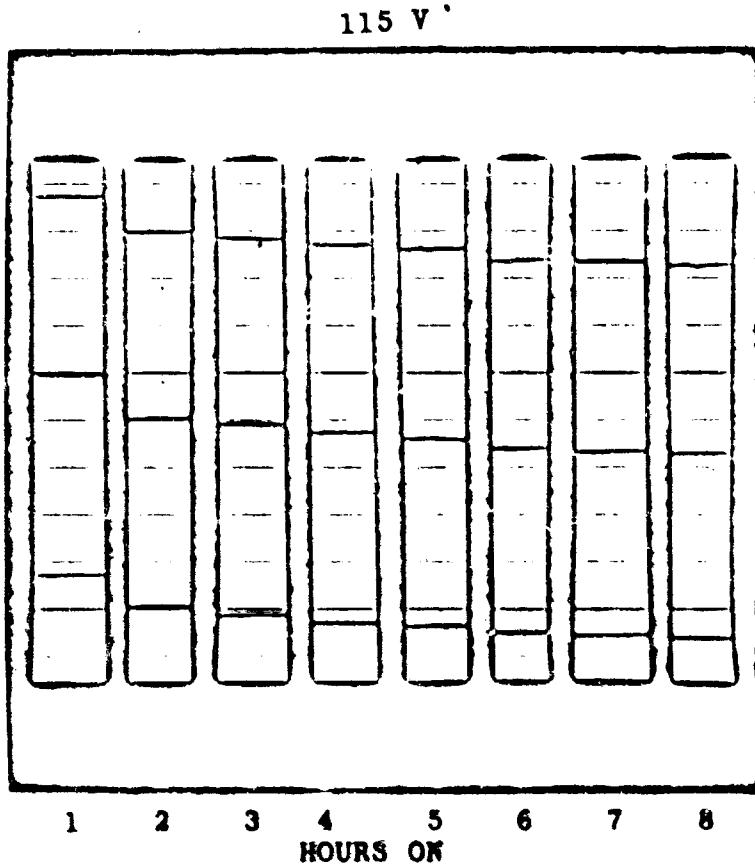


FIG. 18 CHART RECORD FOR NO CHANGE IN LINE VOLTAGE

51

Attachment 2

measurements made during the 30-minute warm-up period. We conclude, therefore, that the Keeler recorder needs little warm-up time which may be expected to be no more than that indicated in Figure 18, as discussed above.

The Stoelting recorder data of Figure 18 shows the presence of drift. The values decreased one full division between the first and second hour after the recorder was turned on. By the 8th hour after the recorder reached 1 3/4 division. Insofar as sensitivity is concerned the pen excursions associated with ΔR were not symmetric, being -4.3 and +3.8. Asymmetry of the same magnitude was noted in measurements made during the first thirty minutes of operation as described above. By the second hour, in Figure 18, the trace became symmetric and sensitivity remained relatively stable.

We conclude that the center value of the Stoelting recorder is subject to a relatively large drift and the effect may be expected to be present during the full eight hours of operation. Sensitivity is relatively stable and free from significant drift after a few minutes warm-up time. An undesirable asymmetric response is present however, which produces negative direction traces too large and positive direction traces too small by 5% during at least the first hour of warm-up.

IX. FACTORS AFFECTING OPERATION

The factors affecting operation have been categorized as calibration, operator controls and adjustments and those remaining "other factors" which the operator does not ordinarily control, such as line power, interference, etc. Of these three categories, the first has been discussed under section IV, CALIBRATION, and section VIII, DRIFT CHARACTERISTICS. The remaining two are treated below.

9.1 Operator Controls and Adjustments

The operator controls are:

- A. Selection of auto-zero or manual-zero mode of operation.
- B. Adjustment of CENTERING control.
- C. Adjustment of SENSITIVITY control.
- D. Adjustment of pen counterweight.

The development of this report required, in the author's opinion, an earlier introduction of items A and B and therefore, these items will not be discussed below but simply referenced. The discussion of the effects of item A appears in section 7.4, Time Constant of auto-ZERO Mode. Item B,

Attachment 2

CENTERING, is described in section 5.5, CENTERING Control Dial, and the associated drift in zero-center tracking under section VIII, DRIFT CHARACTERISTICS.

9.1.1 Adjustment of Sensitivity Control

The relationship between the setting of the SENSITIVITY control and response of the recorder to change in subject resistance, expressed in divisions per kilohm, is shown in the two graphs of Figure 19. The data were obtained as follows:

RO	100 k Ω
+ ΔR	adjusted to produce a -4 division deflection
ZERO SENSITIVITY	manual set at the individual values listed on the abscissae of Figure 19
CENTERING	adjusted for +2-division

By stepping the subject resistance from RO to RO+ ΔR for various settings of the SENSITIVITY control, in each instance a corresponding value of ΔR was selected to produce a 4-division deflection. The change in deflection, 4 divisions, divided by the corresponding ΔR provided the plotted ordinate values for the various SENSITIVITY settings.

The Keeler recorder plot appeared so irregular that three settings of points were obtained using two different operators. Reasonably good agreement was obtained for each setting. The confidence gained by this procedure justifies fitting an irregular curve to these points. There appears to be a prominent undesirable two-cycle variation present in the plot. The conclusion is that the SENSITIVITY (Reactivity) control dial does not provide a convenient means for estimating sensitivity. A curve, like that in Figure 19, would be necessary to make such use of the dial.

The Stoelting recorder plot is relatively smooth and passes through zero at the origin. The 100% values of both curves agree well with the static calibration curves.

We conclude that the Stoelting recorder SENSITIVITY control dial calibration is sufficiently linear to provide a convenient means for estimating sensitivity.

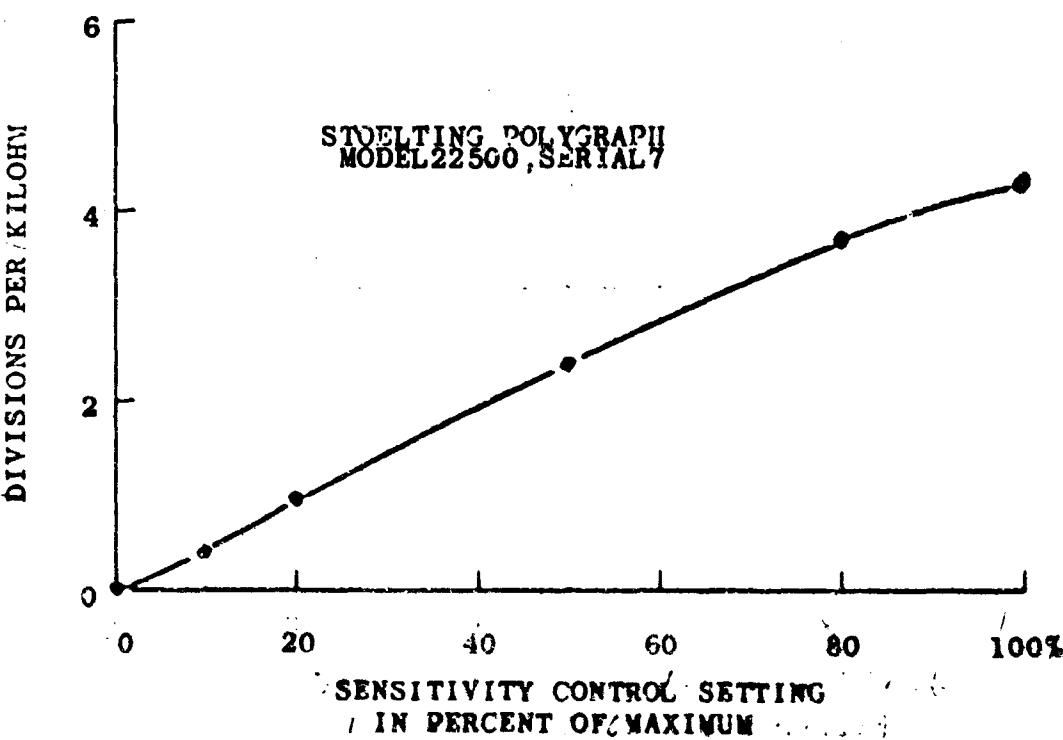
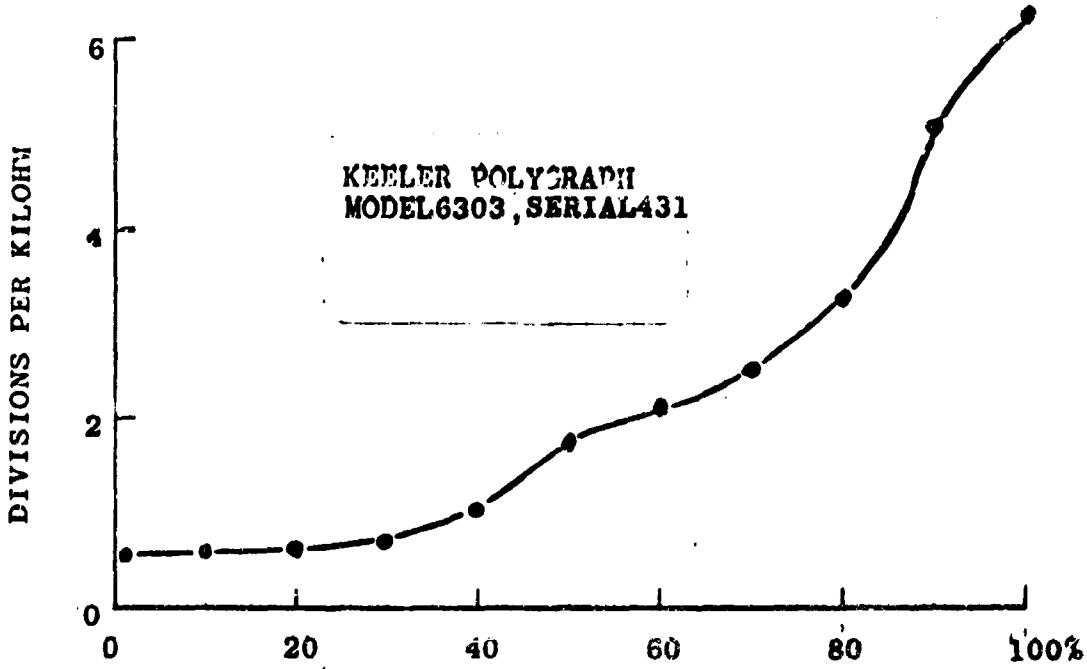


FIG. 19 CALIBRATION OF SENSITIVITY CONTROL

9.1.2 Adjustment of Pen Weight

Pen weight has a pronounced effect on the character of the records produced by the Keeler recorder. Examples of this effect are given below. The problem of selection of a satisfactory pen counterweight adjustment becomes important and is explored.

Pen weight is adjusted by the operator through rotation of a knurled nut counterweight which screws onto a threaded shaft which extends to the rear of the pen cradle. The right-hand thread causes the pen weight to be increased as the counterweight is rotated clockwise (CW) as viewed from behind the pen mechanism. The Keeler pen threaded shaft has 2.25 threads per mm or approximately 57 threads per inch and the Stoelting, 56 threads per inch.

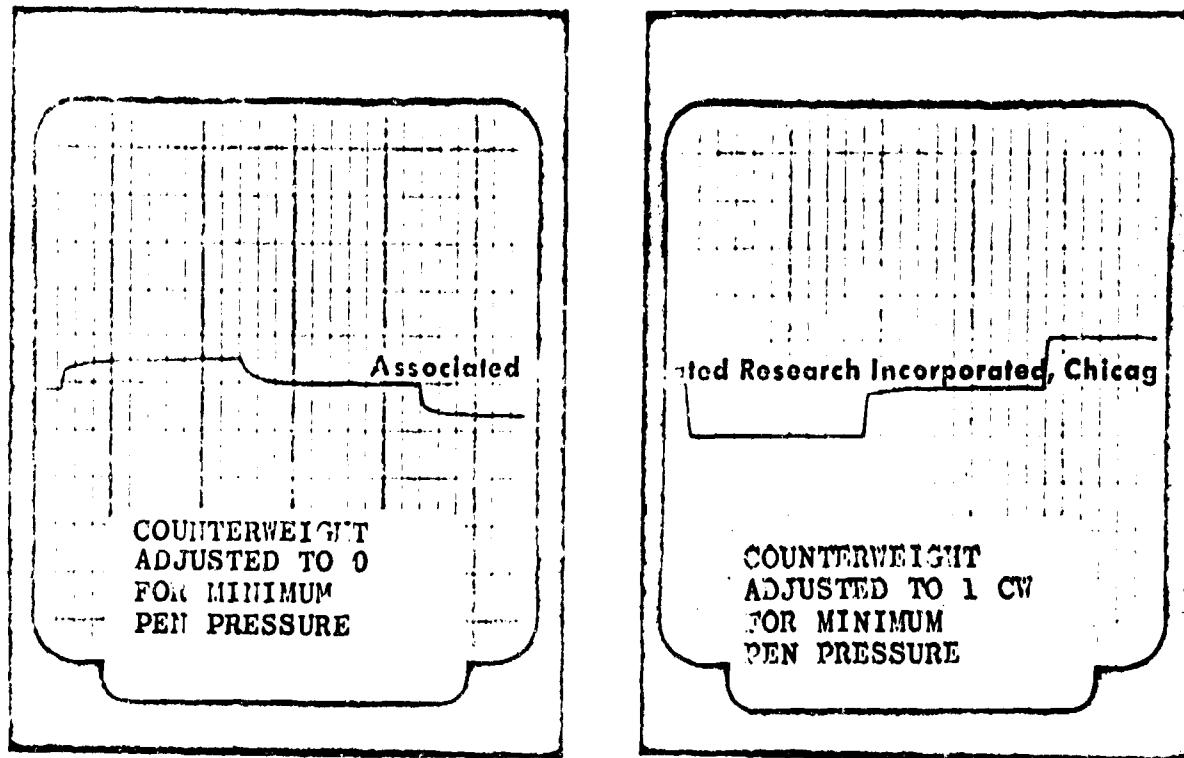
There were several difficulties experienced in running this portion of the study. The Keeler recorder ink well is so close to the pen counterweight that extreme care was required when making the frequent adjustments to avoid dipping the finger tips into the ink. The strip chart in the Stoelting recorder does not always lie flat and during operation, there is a slight tendency to buckle which results in the paper "snapping" the pen away from the paper surface, thus interrupting the trace. This was corrected by adding a follower roller similar to that used in the Keeler recorder. This roller had no other effect than to eliminate the tendency of the paper to buckle.

9.1.2.1 Minimum Pen Weight.

Pen weight is specified in this report by giving the number of CW turns the counterweight is rotated from a reference zero position. The reference zero was established by adjustment of the counterweight to provide lightest pen weight which would provide a continuous ink record from a stationary pen for at least thirty seconds. The thirty-second time interval requirement is essential, otherwise, the zero reference adjustment would often be too light and the pen would rise from the paper after a few seconds.

After determination of the zero-reference counterweight position, ten-second step changes in subject resistance were applied to cycle preselected fixed pen excursions. At light pen weight adjustments, the pen would lift--depending upon deflection. To miss this, the pen counterweight was adjusted to obtain the minimum pen weight adjustment for each magnitude of the cycling pen deflection. The strip charts are shown in Figures 20A, 20B, 20C, and 20D for the Keeler recorder and Figure 21 for the Stoelting.

20A



KEELER POLYGRAPH
MODEL 6303, SERIAL 431

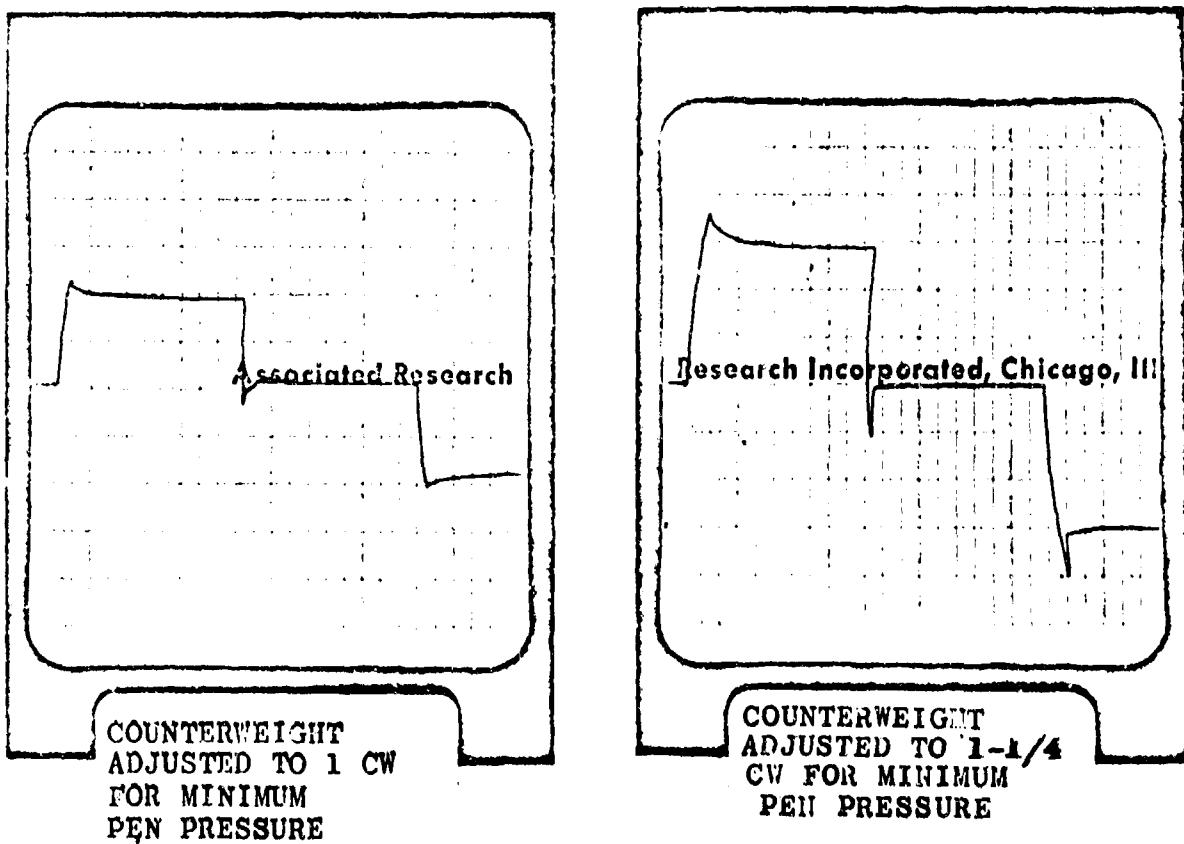
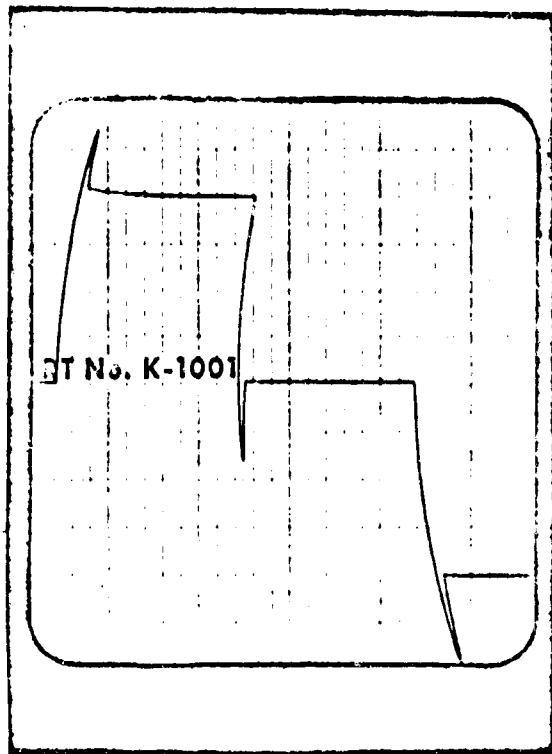
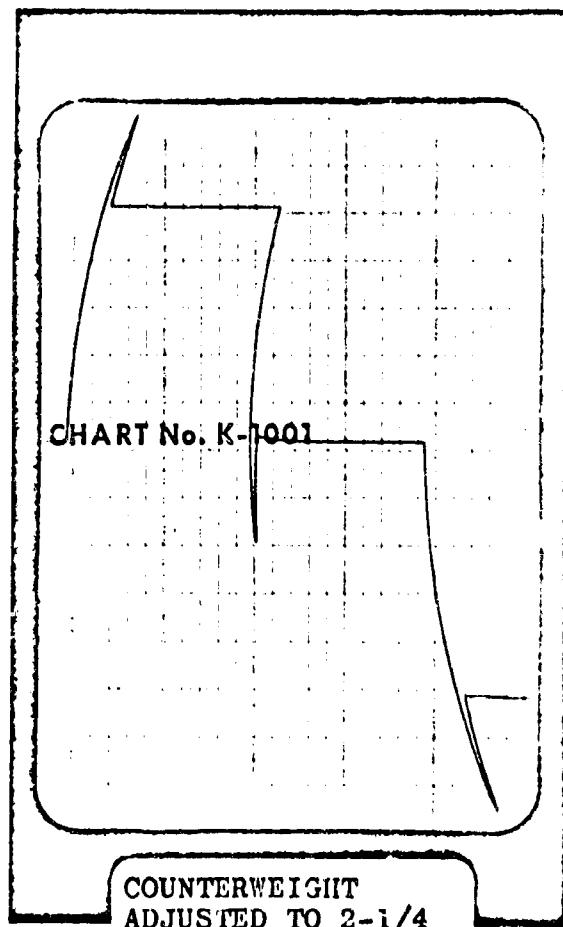


FIG. 20A TYPICAL CHART RECORD FOR MINIMUM PEN WEIGHT.

KEELER POLYGRAPH
MODEL 6303, SERIAL 431



COUNTERWEIGHT
ADJUSTED TO 1-5/8
CW FOR MINIMUM
PEN PRESSURE

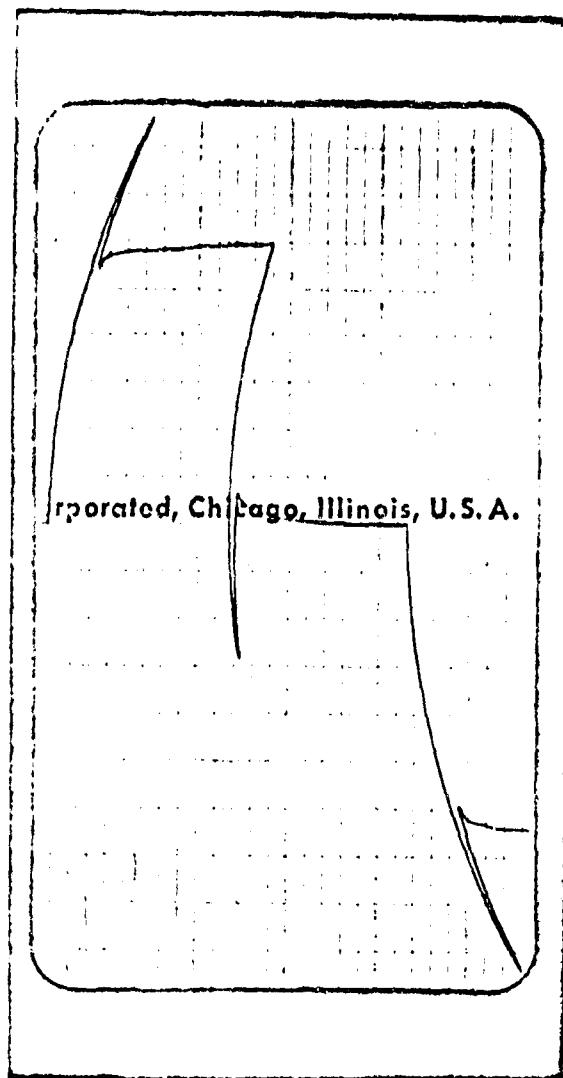


COUNTERWEIGHT
ADJUSTED TO 2-1/4
CW FOR MINIMUM
PEN PRESSURE

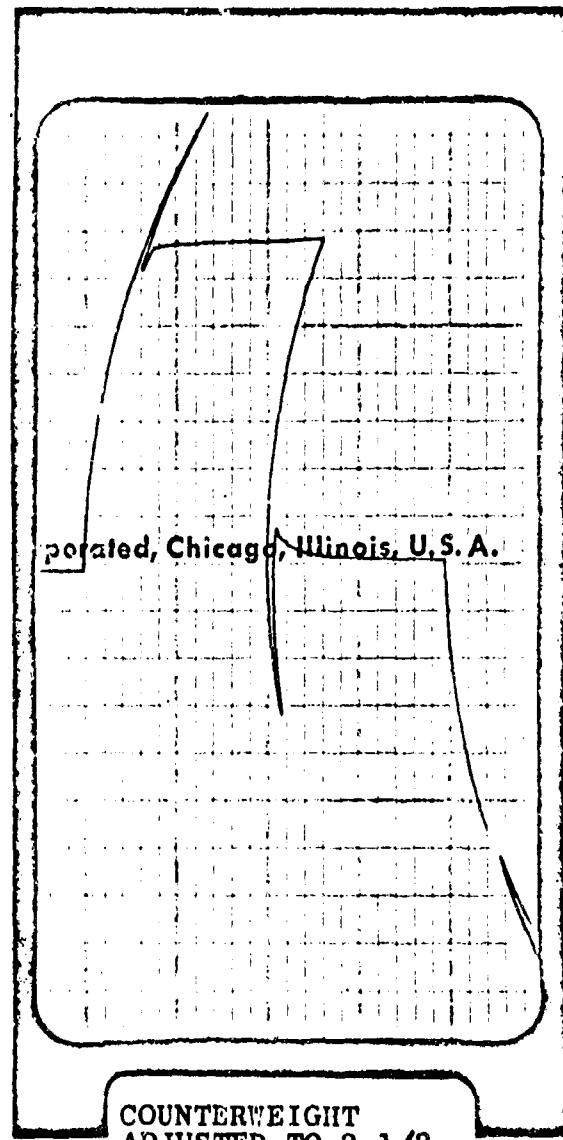
FIG. 20B TYPICAL CHART RECORD FOR MINIMUM PEN WEIGHT.

KEELER POLYGRAPH
MODEL 6303, SERIAL 431

20-



COUNTERWEIGHT
ADJUSTED TO 2-1/4
CW FOR MINIMUM
PEN PRESSURE

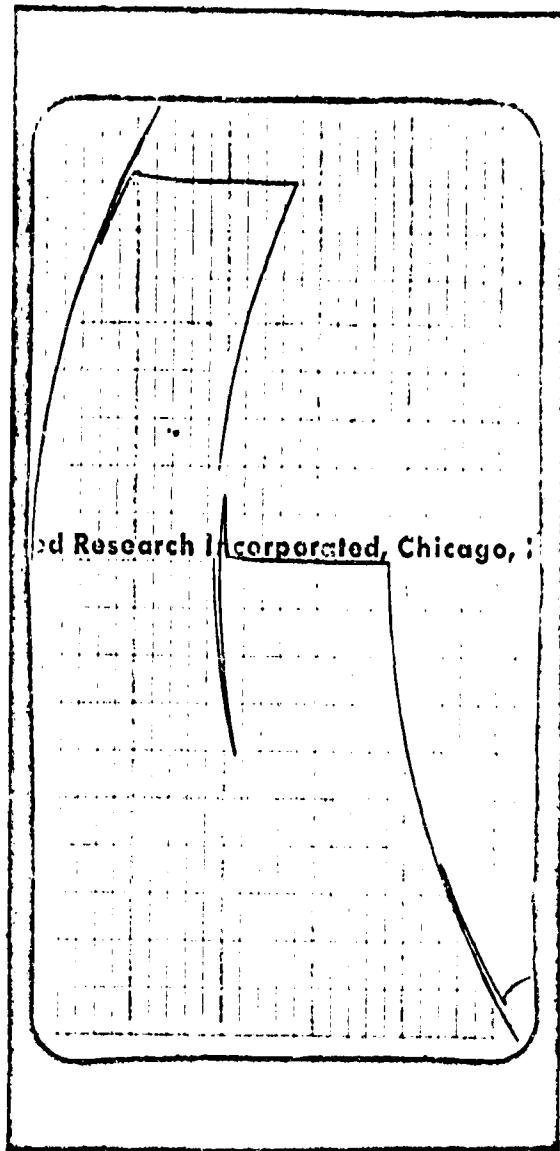


COUNTERWEIGHT
ADJUSTED TO 2-1/2
CW FOR MINIMUM
PEN PRESSURE

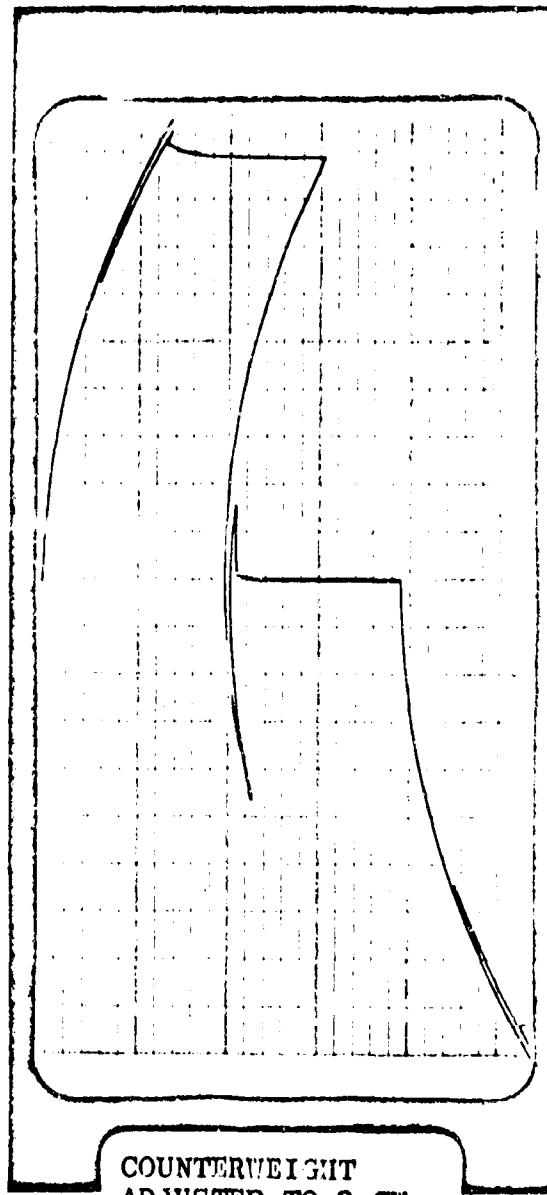
FIG. 20C TYPICAL CHART RECORD FOR MINIMUM PEN WEIGHT.

KEELER POLYGRAPH
MODEL 6303, SERIAL 431

222



COUNTERWEIGHT
ADJUSTED TO 2-7/8
CW FOR MINIMUM
PEN PRESSURE



COUNTERWEIGHT
ADJUSTED TO 3 CW
FOR MINIMUM
PEN PRESSURE

FIG. 20D TYPICAL CHART RECORD FOR MINIMUM PEN WEIGHT.

STOELTING POLYGRAPH
MODEL 22500, SERIAL 7

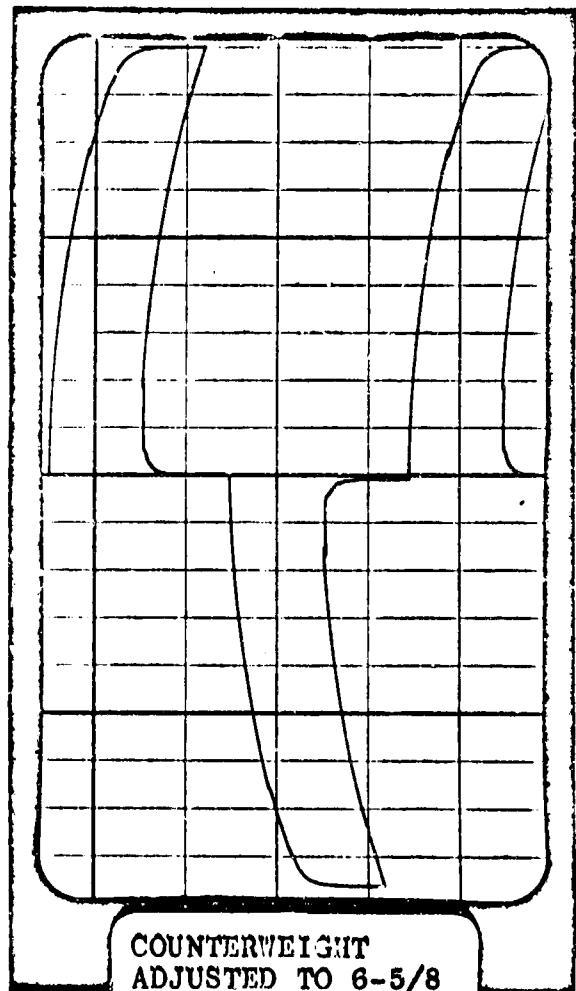
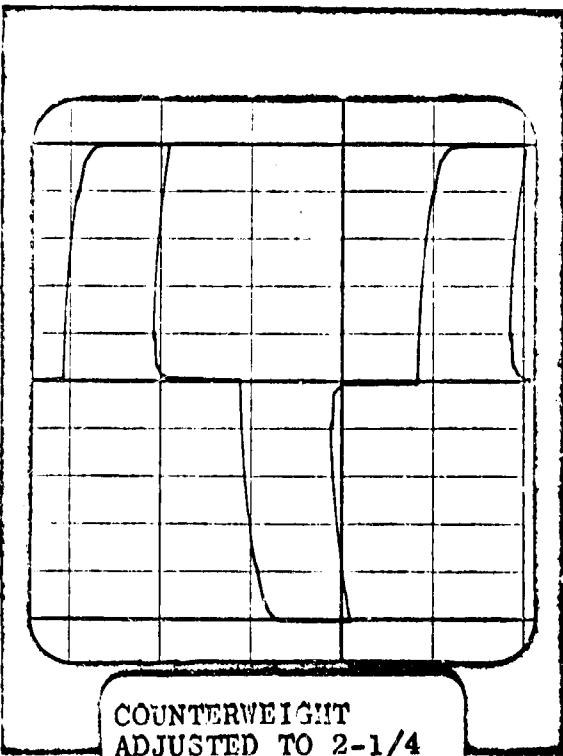
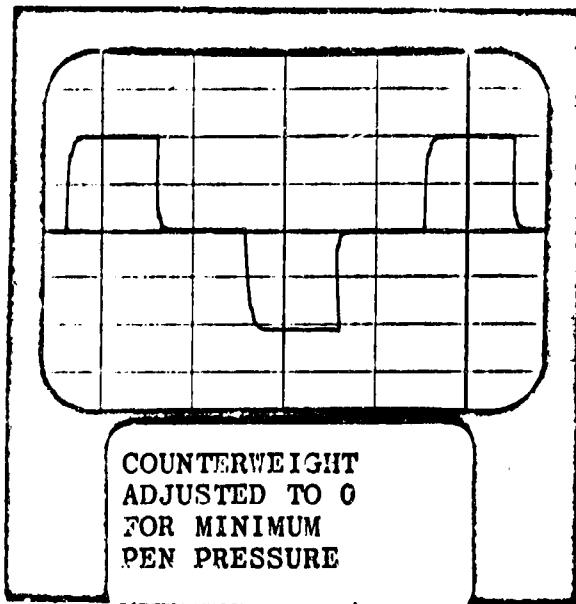
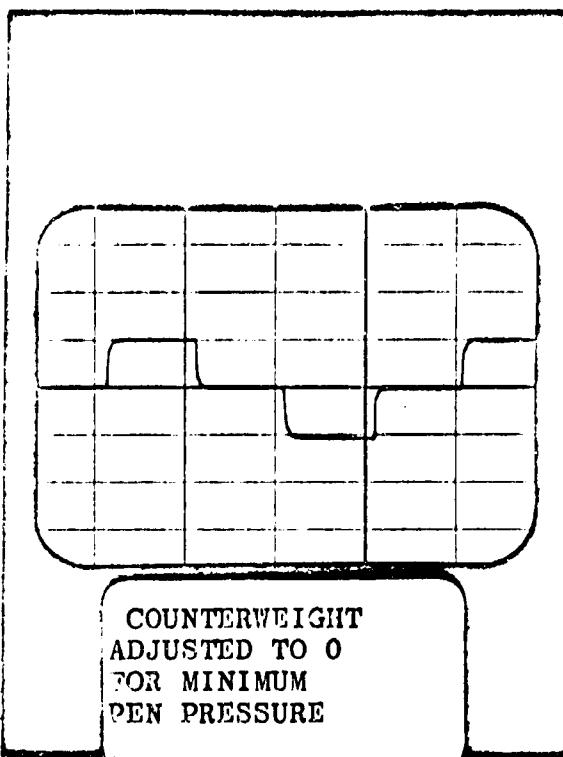


FIG. 21 TYPICAL CHART RECORD FOR MINIMUM PEN WEIGHT.

Attachment 2

In Figure 20A the $\pm 1/2$ division step deflections required no increase in pen weight. Notice that the step changes do not overshoot but gradually approach a fixed deflection which is characteristic of an overdamped system. The ± 1 division step deflections required an increase in pen weight as indicated by the counterweight adjustment 1 CW turn. In this instance the trace neither undershoots nor overshoots which is characteristic of a critically damped system. For ± 2 division deflections the minimum pen weight requirement remains unchanged and overshoot occurs indicating an underdamped system. The remaining charts through Figure 20D with increases in deflection up to ± 9 divisions show increasing overshoot and minimum pen-weight requirements. It is interesting to note that in the ± 4 -division deflection chart of Figure 20B that the overshoot is 2 divisions and the appearance of the recovery trace is typical of critical damping.

Figure 21 shows examples of chart records derived in a similar manner for the Stoelting recorder. The Stoelting recorder strip chart records indicate that the pen deflections are slightly overdamped and remain so, independent of magnitude of deflection.

A plot of pen deflection versus minimum pen weight expressed as counterweight position is given in Figures 22 and 23. They show only approximate relationships as indicated by the spread of sets of points. These figures are intended to indicate the range and sensitivity of each recorder to minimum pen weight adjustments.

The above described observations were followed by an examination of the effects of pen weight adjustments on the character of the strip chart record.

9.1.2.2 Effects of Pen Weight

A series of strip-chart records are shown in Figures 24 and 25 as examples of responses to step changes in subject resistance, with each frame representing a different pen weight as indicated. The conditions were as follows:

RO	100 k Ω
ΔR	1 k Ω
DWELL TIME	0.5 seconds
ZERO	manual
SENSITIVITY	adjustment described below
CENTERING	zero

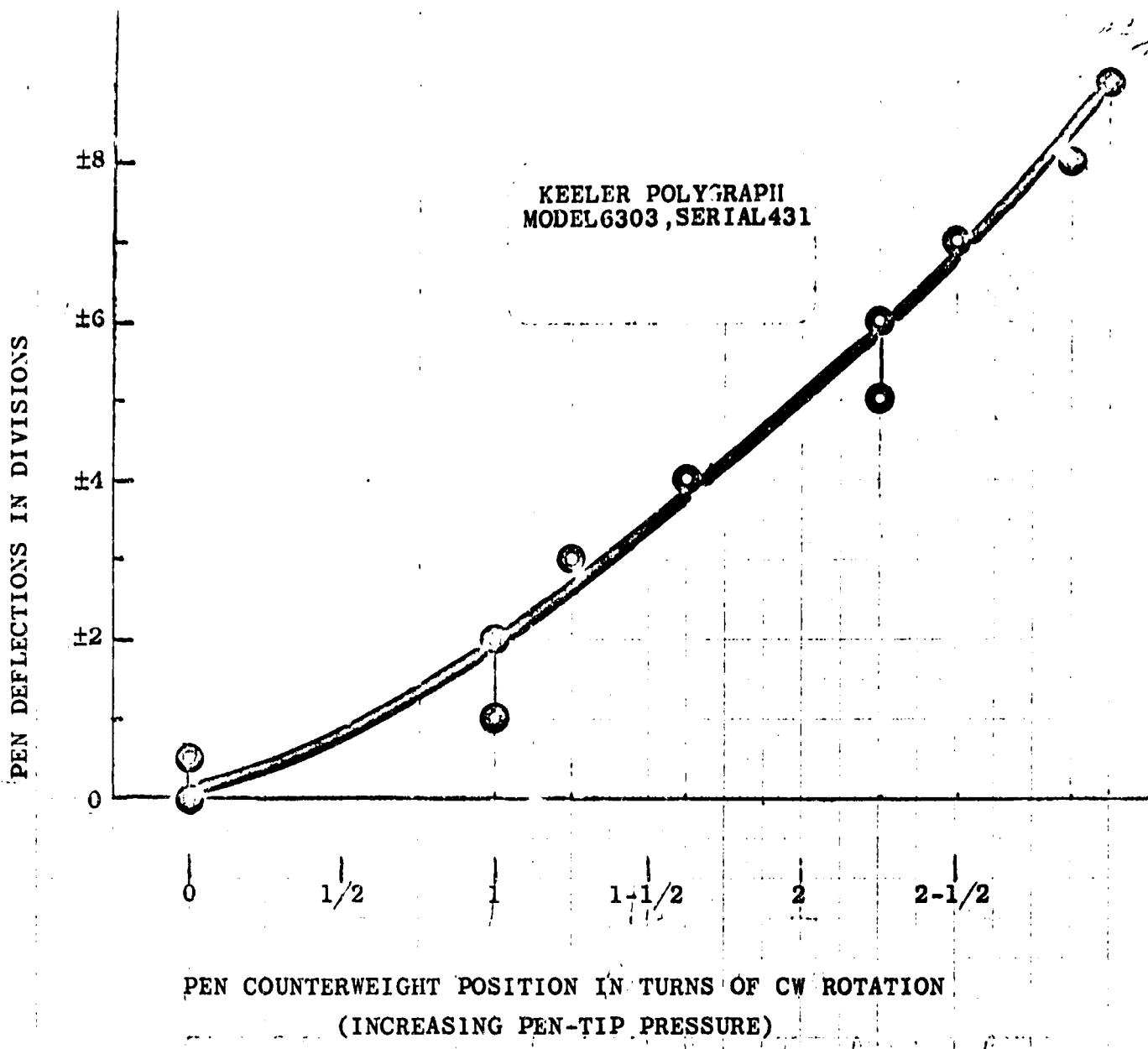
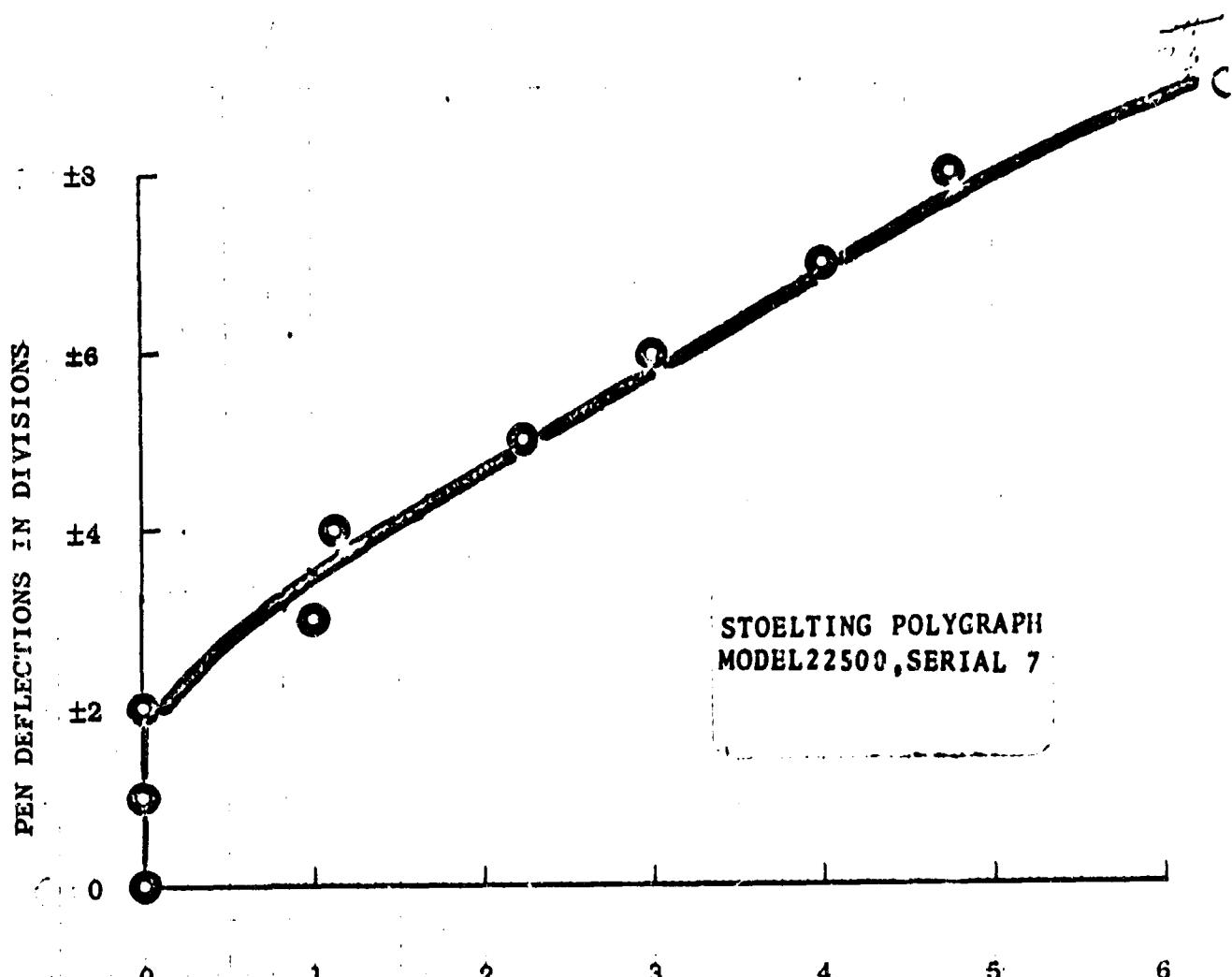


FIG. 22 DEFLECTION RANGE FOR MINIMUM PEN WEIGHT ADJUSTMENTS
NECESSARY TO AVOID INK SKIPS IN SLOW STEP-CHANGE
RECORDS.



PEN COUNTERWEIGHT POSITION IN TURNS OF CW ROTATION
(INCREASING PEN-TIP PRESSURE)

FIG. 23

DEFLECTION RANGE FOR MINIMUM PEN WEIGHT ADJUSTMENTS
NECESSARY TO AVOID INK SKIPS IN SLOW STEP-CHANGE
RECORDS.

KEELER POLYGRAPH
MODEL 6303, SERIAL 431

STOELTING POLYGRAPH
MODEL 22500, SERIAL 7

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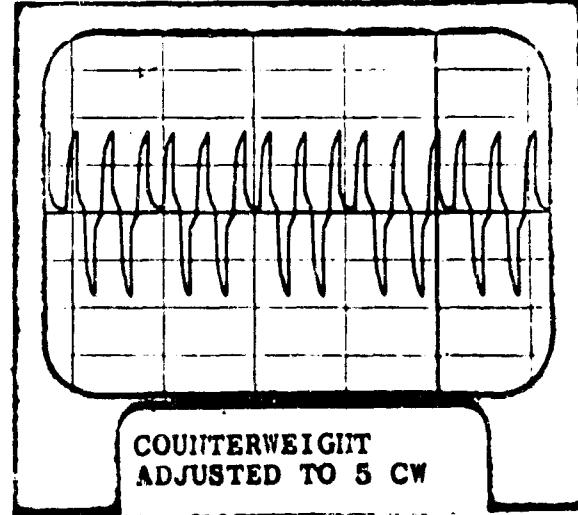
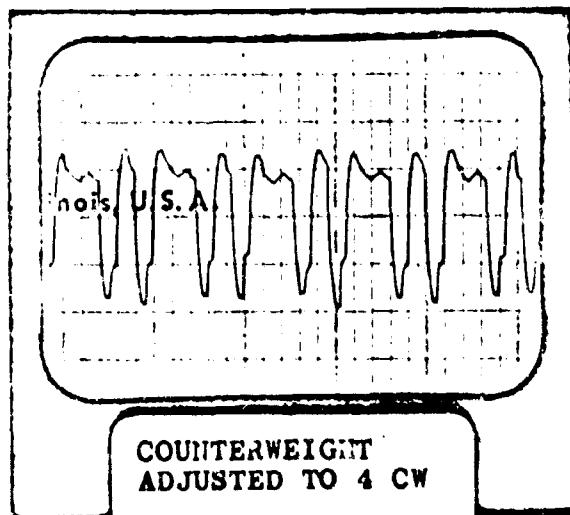
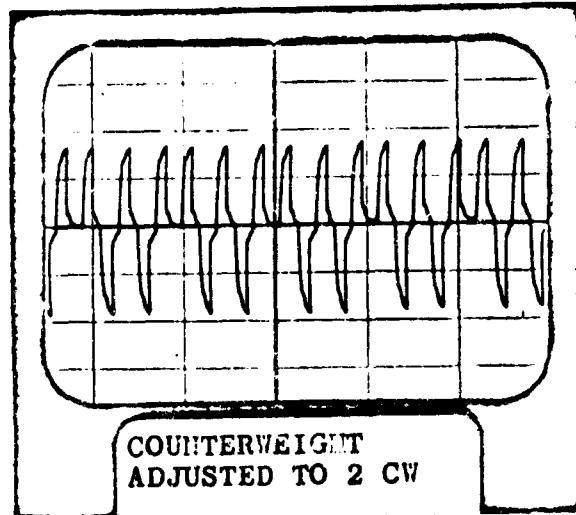
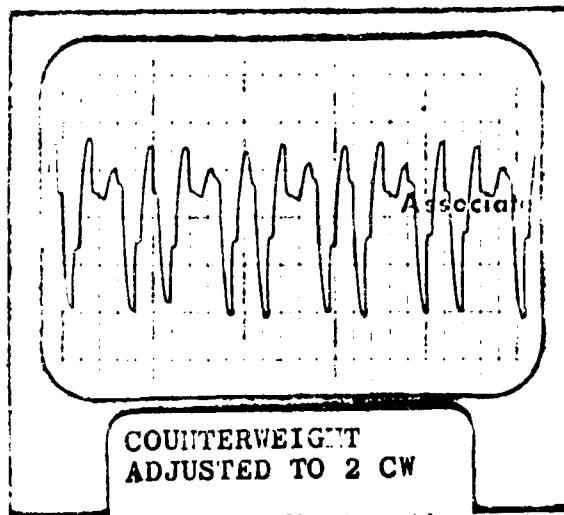
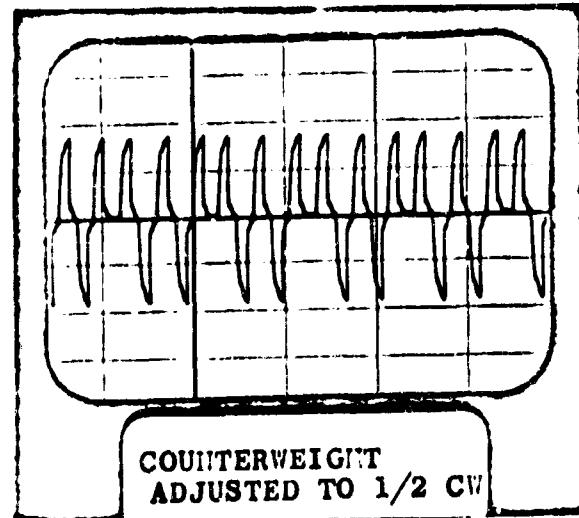
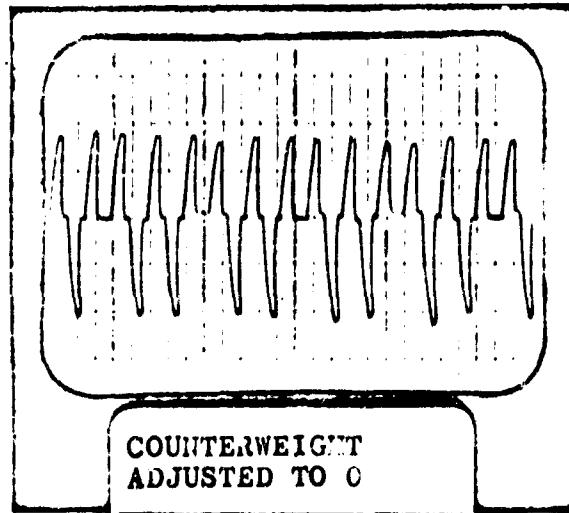
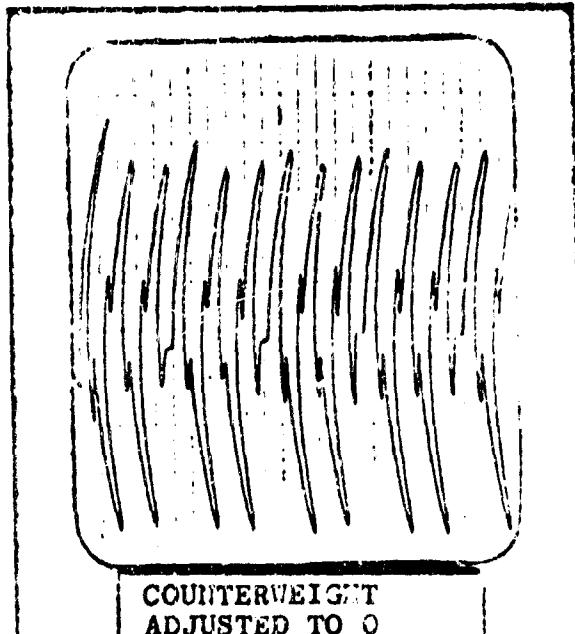


FIG. 24 TYPICAL CHART RECORDS FOR DIFFERENT PEN WEIGHT
ADJUSTMENTS.

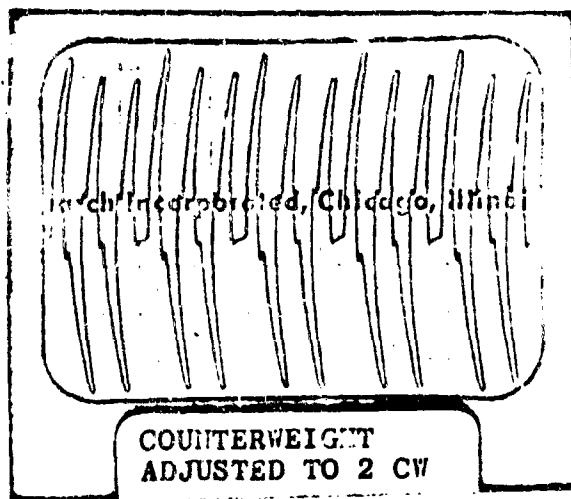
KEELER POLYGRAPH
MODEL 6303, SERIAL 431

STOELTING POLYGRAPH
MODEL 22500, SERIAL 7

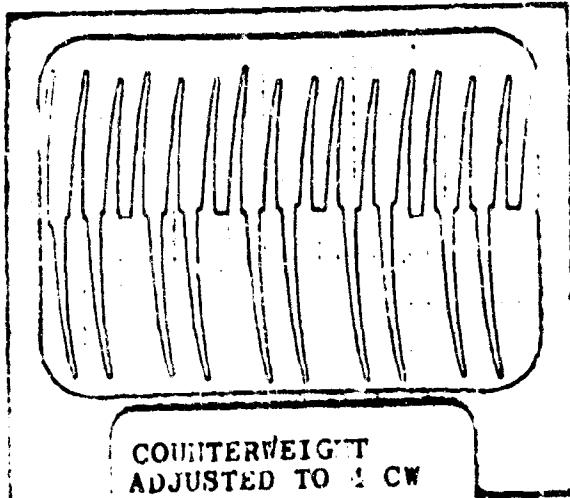
25



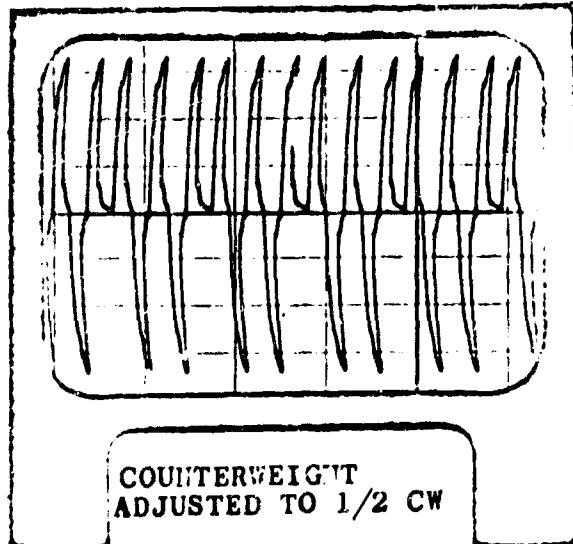
COUNTERWEIGHT
ADJUSTED TO 0



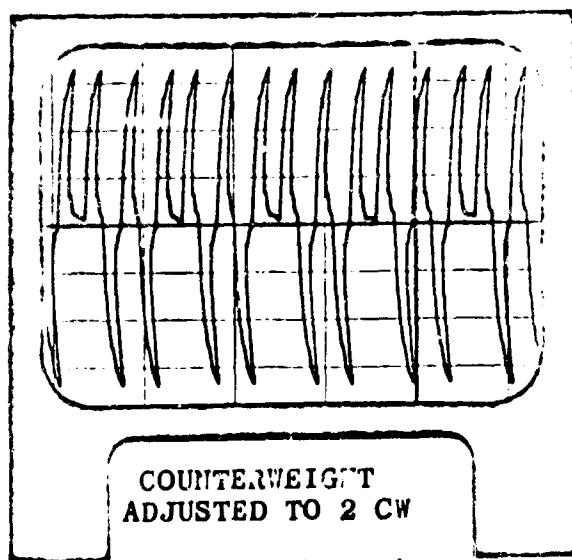
COUNTERWEIGHT
ADJUSTED TO 2 CW



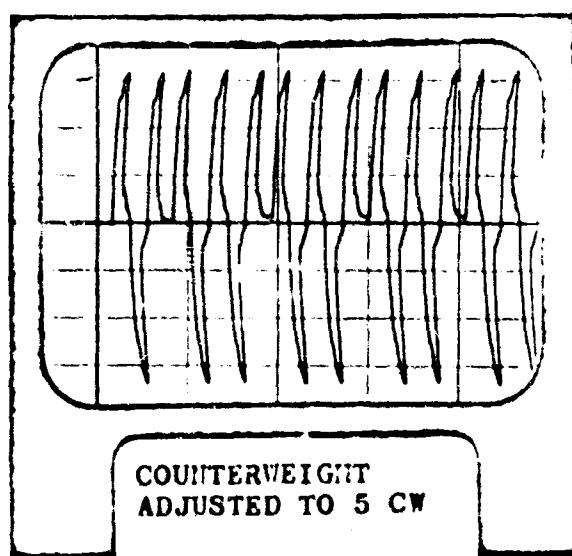
COUNTERWEIGHT
ADJUSTED TO 4 CW



COUNTERWEIGHT
ADJUSTED TO 1/2 CW



COUNTERWEIGHT
ADJUSTED TO 2 CW



COUNTERWEIGHT
ADJUSTED TO 5 CW

FIG. 25 TYPICAL CHART RECORDS FOR DIFFERENT PEN WEIGHT
ADJUSTMENTS.

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Attachment 2

The sensitivity adjustments for Figure 24 were determined with the Keeler recorder by first setting the pen weight to a minimum (counterweight adjusted to zero) and then varying the SENSITIVITY control while observing the character of the trace. For deflections in the order of 1.6 the trace took on the appearance of a critically damped system, for smaller deflections the trace appeared overdamped and for larger deflections, underdamped. In this way the deflection represented in Figure 24 was determined. A similar pen counterweight and deflection amplitude was recorded also, for the Stoelting recorder, as shown in the top right frame.

The effect of increasing the pen weight is shown in the remaining frames, reading down Figure 24. Very significant changes were produced in the Keeler traces. The increased pen drag mainly affected the return to center zero. With counterweight weight adjusted to 4 turns CW, the trace bears little resemblance to the corresponding subject resistance changes presented at the input terminals.

The Stoelting recorder produced an overdamped trace which follows subject resistance step changes reasonably well and the character of the trace is essentially independent of the pen weight range shown.

A comparable set of chart records given in Figure 25 was obtained beginning with a relatively heavy pen weight (4 turns CW) and an amplitude adjustment to produce a critically damped appearance of the trace for the Keeler recorder. A deflection amplitude of approximately 3 divisions was thus selected. The effects of decreasing pen weight are shown in the remaining frames.

Again the traces of the Keeler were affected noticeably. The character of the trace became that of an underdamped system with the more pronounced overshoot occurring as the pen was driven in the near zero region. These traces do however, provide a reasonable representation of the changes in subject resistance and are not nearly so degenerate as those obtained in Figure 24.

The comparable Stoelting recorder traces have the same general appearance in Figure 25 as those in Figure 24 which were discussed in the preceding paragraph. The effects of underdamped operation are slightly larger for the former and the trace indicates that at least two time constants are present and affect the fine structure of the trace. This detail is not considered of sufficient importance, however, to be included here in the discussion of the general appearance of the trace which reflects reasonably well the changes in subject resistance presented at the input terminals.

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Attachment 2

A number of additional strip charts were recorded and the results were summarized in Figure 26. These results show the relationship between pen deflection and pen counterweight adjustment which resulted in critically damped performance for the Keeler recorder. Examples of the chart appearance have already been presented in the upper left frames of Figures 24 and 25.

The interrelated effects of pen weight adjustments and deflection are complex and, in general, are sufficiently large as to degenerate the ability of the Keeler recorder to provide consistent representation of subject resistance changes. It is especially significant to note that the operator manual which accompanied this recorder makes the following statement regarding pen balance under "STEP No. 17. Balance the pens for minimum weight on the chart for the maximum pattern. This is done by turning the counterbalance nuts (No. 12) behind the pen pivots so that the nut moves away from the pivot. If the nut is turned too much, the pen may rise off the chart or start floating. If that happens, merely screw the nut back toward the pivot a few turns." This procedure allows considerable freedom in pen counterweight adjustment, and especially for small deflections where the system is overdamped, the appearance of the chart recorder would be strongly influenced by the operator's choice of pen weight adjustment. See Figure 27.

9.2 Other Factors

Among the remaining factors which may affect performance are those which can be considered environmental influences. It is not within the scope of the present evaluation to study the effects of the obvious environmental factors such as ambient temperature and relative humidity. These factors fall within the range from 70°F to 78°F and approximately 10% to 40% RH variations normally associated in an electronics laboratory.

The effects of hum pick-up were not serious and have been discussed in Section 4.1, Review of Sensitivity or Pick-up.

9.2.1 Line Voltage

The effects of changes in line voltage of ±10% were examined using a procedure similar to that for the study of drift under section VIII, DRIFT CHARACTERISTICS, which produced Figure 18. In the present study, the line voltage was deliberately changed as indicated in Figure 28 for the Keeler recorder and Figure 29 for the Stoelting. The solid horizontal lines are traces of the pen deflection. The dashed lines were added to repeat the span appearing in the 115 V record. Thus the difference between the dashed line and solid line is a measure of the change in sensitivity to the fixed step change in subject resistance. Referring to Figure 28, the record for the Keeler recorder, the left-most frame shows a reference record trimmed to zero-center deflection

21
22

KEELER POLYGRAPH
MODEL 6303, SERIAL 431

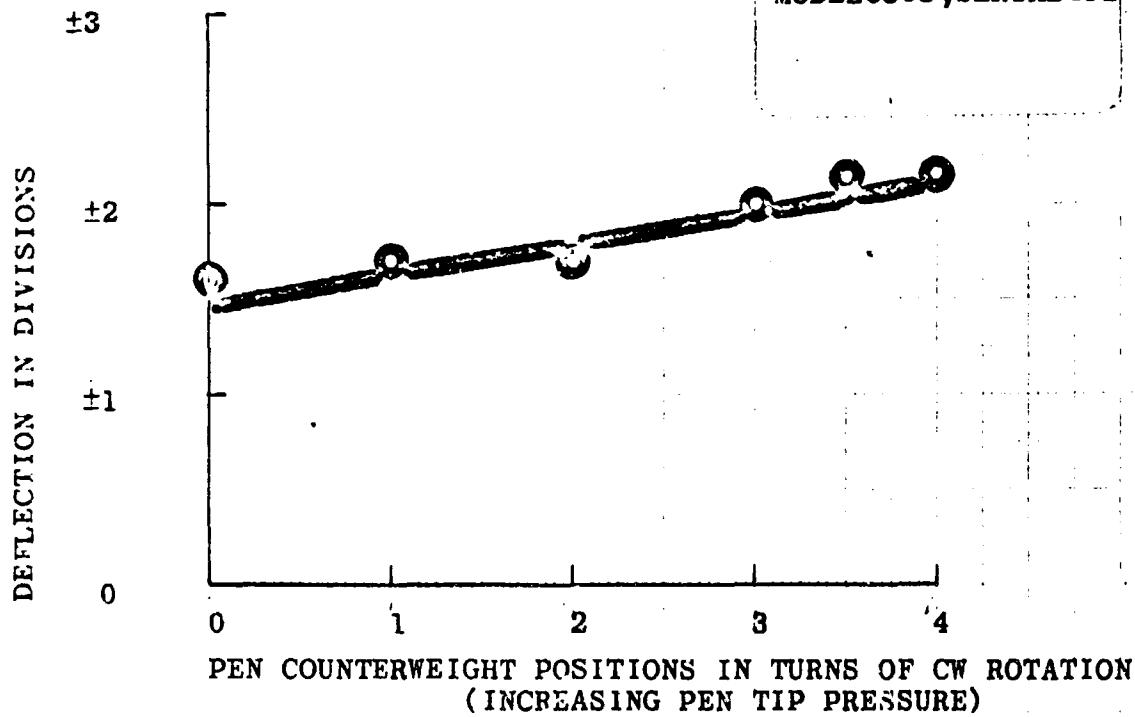


FIG. 26 MAGNITUDES OF DEFLECTION VS. PEN WEIGHT ADJUSTMENTS
ARE SHOWN FOR CRITICAL DAMPING.

KEELER POLYGRAPH
MODEL 6303, SERIAL 431

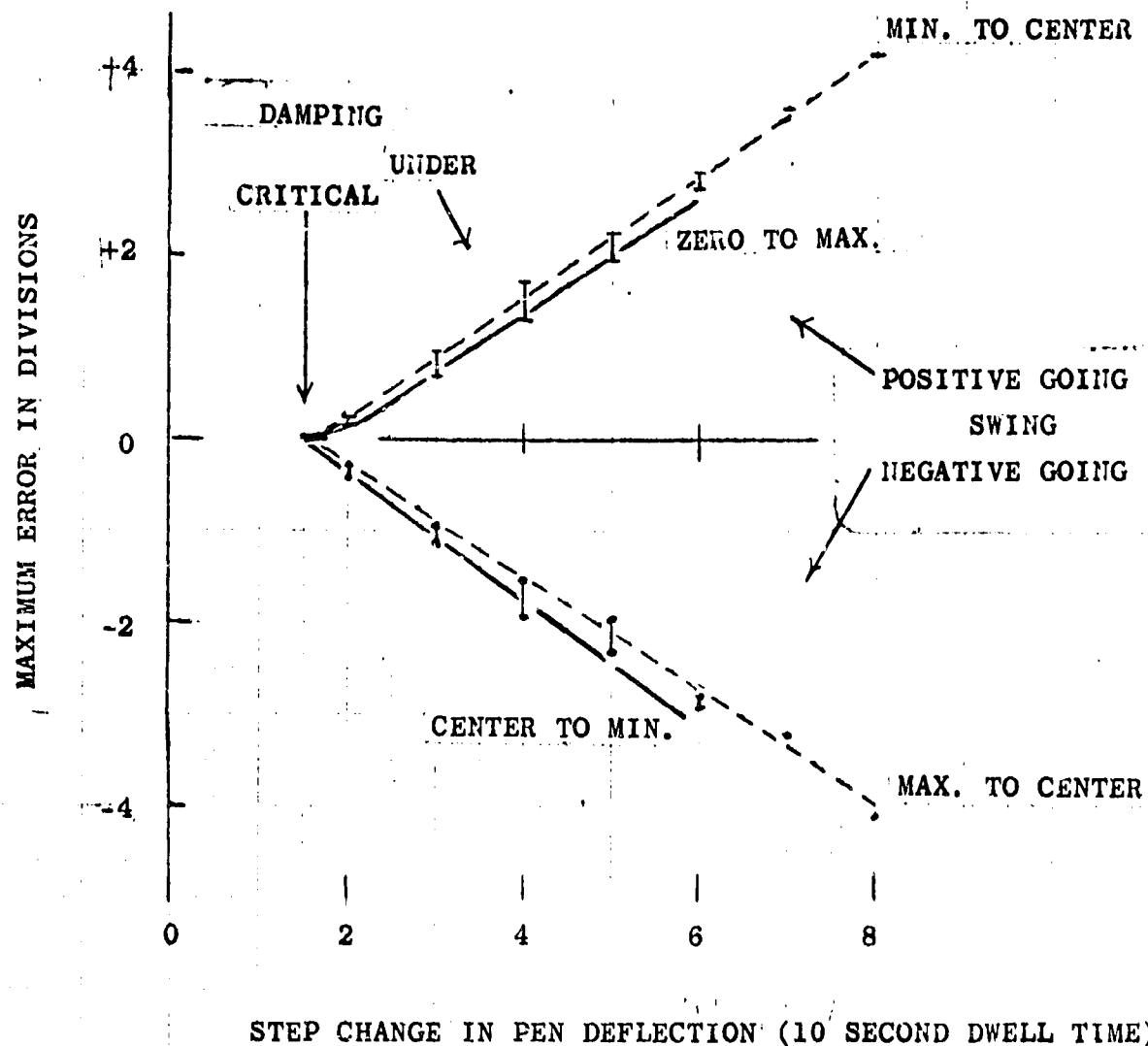


FIG. 27

MAXIMUM OVERSHOOT ERROR, THE DIFFERENCE BETWEEN INITIAL PEN EXCURSION AND FINAL (10 SECOND) VALUE FOR STEP CHANGE IN INPUT. MINIMUM PEN WEIGHT ADJUSTMENT FOR EACH STEP.

26

KEELER POLYGRAPH
MODEL 6303, SERIAL 431

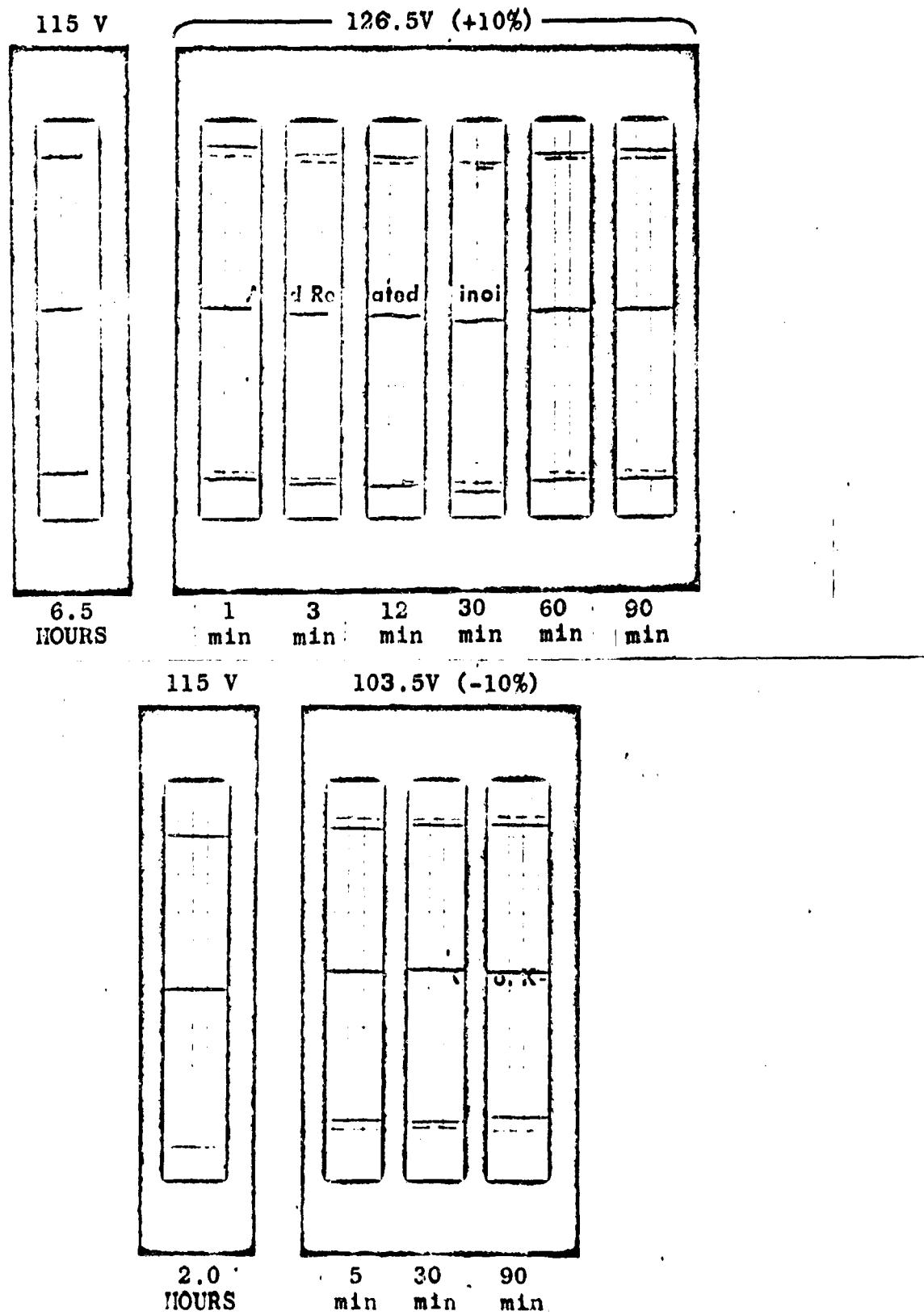
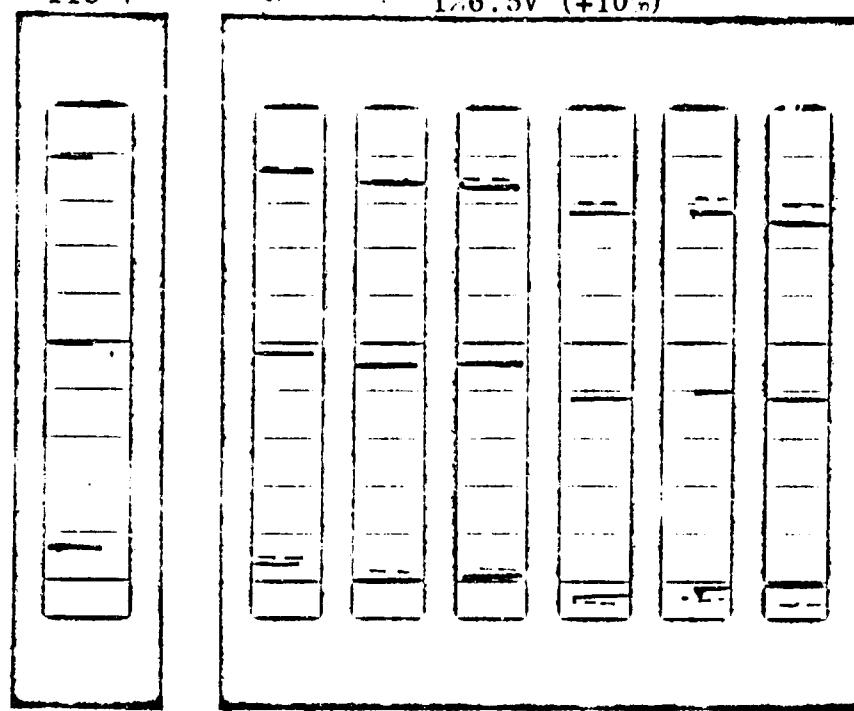


FIG. 28 CHANGE IN CHART RECORD FOR +10% AND -10%
CHANGE IN LINE VOLTAGE

STOELTING POLYGRAPH
MODEL 22500, SERIAL 7

115 V

126.5V (+10%)



115 V

103.5V (-10%)

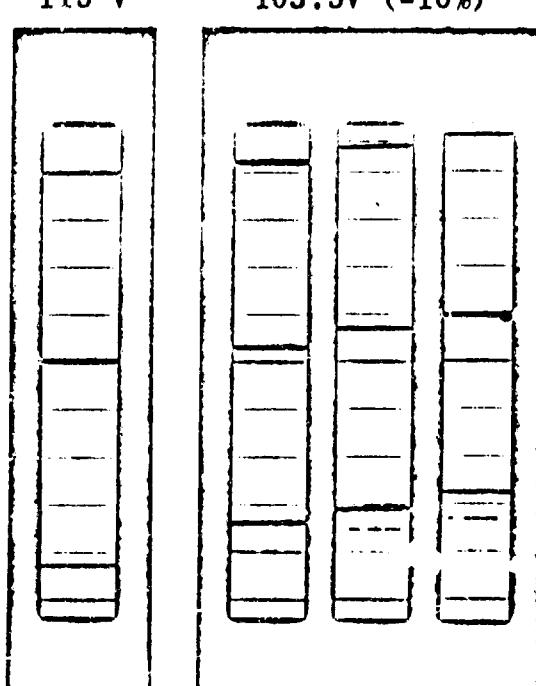


FIG. 29

CHANGE IN CHART RECORD FOR +10% AND -10%
CHANGE IN LINE VOLTAGE

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Attachment 2

and nearly +4-divisions after 6.5 hours of warm-up time. The line voltage was abruptly increased +10% of 126.5 volts. The sampling records shows a maximum of -0.3 divisions change in zero-center and this small change cannot be considered significant in light of the drift recorded in Figure 18 where the line voltage remained fixed. The span between the extreme traces increased and remained larger thus indicating that the sensitivity was increased by approximately 5% and its attributable to a 10% increase in line voltage.

The lower traces of Figure 29 show a significant change in zero-center (approximately +1 division shift) and a decrease in sensitivity, the change in sensitivity being somewhat more than -5% for a -10% change in line voltage.

Similar records for the Stoelting recorder in Figure 29 show pronounced shift in zero-center of -1.2 divisions for a +10% change in line voltage and +1.0 division for a -10% change in voltage. These observations would seem to imply a casual relationship but strong doubts exist in light of the relatively large drift in zero-center of Figure 18 where no change in line voltage was present.

The relationship between sensitivity and change in line voltage is more obvious. The 10% increase in line voltage resulted in a 10% decrease in sensitivity after 90 minutes at the higher voltage. The -10% change in line voltage produced a somewhat similar change (10% decrease). These data show that either an increase or decrease in line voltage (from 115 Volts) produces a decrease in sensitivity which is significant when compared with the relatively stable sensitivity for fixed line voltage, as shown in Figure 18.

The Keeler recorder appears to be less affected by changes in line voltage. The Stoelting recorder operation is appreciably more sensitive to line voltage. The zero-center has an inherent tendency to drift. These drifts are so large as to make it difficult to establish a relationship between zero-center and change in line voltage.

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Attachment 2

APPENDIX I

Three separate systems were used to study the polygraph recorder operating characteristics. Block diagrams of the systems are shown in Figure 30. The input fixture provided a convenient means for connection of the recorder under test to any one of the three input sources.

For the source, "Input Subject Resistance," the recorder under test was connected to precision resistors through the switching chassis. The latter is a flexible switching unit for programming automatic step changes in input resistance and is described in Appendix II.

For the source, "Input DC Voltage," a settable and monitored dc voltage was supplied to attenuators which provided precision step changes as small as 0.1 db. The system was compact and battery operated to avoid interference through ground loops. The input fixture provided a circuit input having fixed attenuation as shown in Figure 31, Schematic Diagram of Input Fixture.

The source, "Input AC Voltage," provided an adjustable frequency sine-wave input voltage with provisions for measurements and control of amplitude. The input fixture contained part of the fixed attenuator.

The input fixture incorporates portions of the voltage attenuators so as to reduce the effects of pick-up present in the leads connected to the input fixture. The circuits are shown in Figure 31.

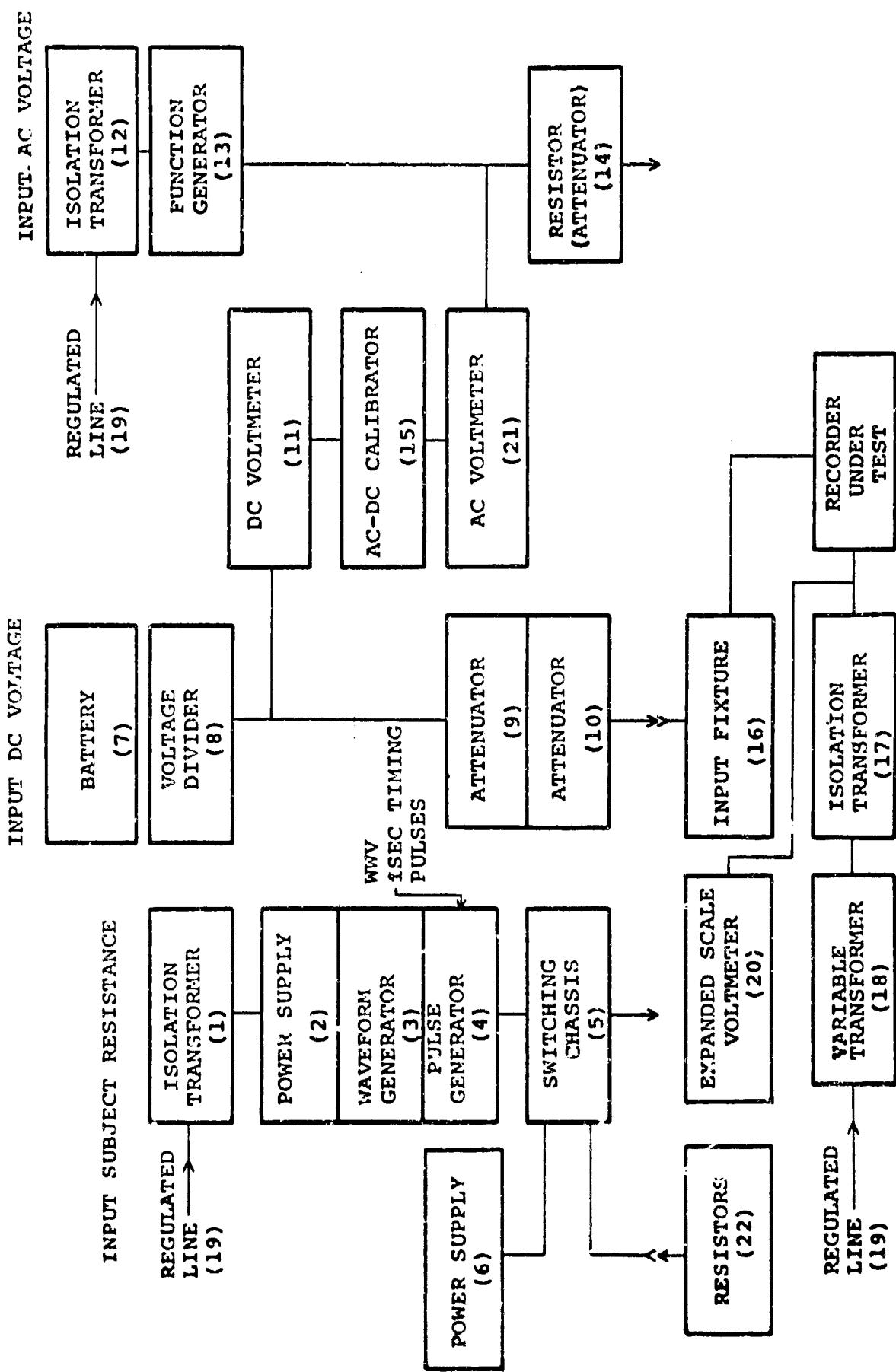


FIG. 30 BLOCK DIAGRAMS OF TEST SYSTEMS

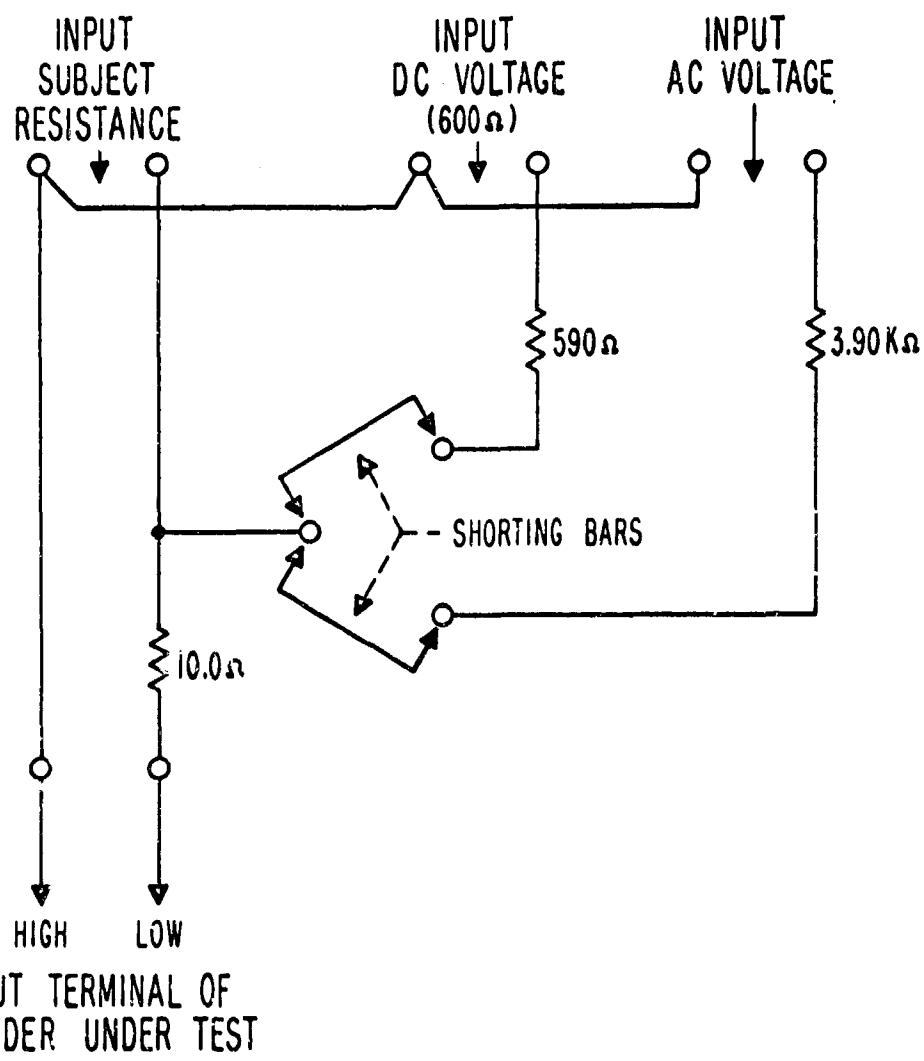


FIG. 31 SCHEMATIC DIAGRAM OF INPUT FIXTURE

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Attachment 2

APPENDIX II

Equipment was built for this study which would automatically provide step changes in subject resistance. The equipment consists of an 11 position stepping switch with controls for stepping the switch through its 11 positions. Each position presents a preselected value of subject resistance. The switch may be stepped 1 position at a time, automatically through 1 cycle of 11 positions, or automatically recycling.

An example of the most commonly used program of resistance values is shown in the strip chart record of Figure 32. The 11 positions of the stepping switch are indicated, 9T, 0, 1 -- 8, 9, 9T, with the corresponding values of subject resistance which produced the chart record. The actual values of resistance used in this example are R_0 equal to $101 \text{ k}\Omega$ and ΔR equal to $1 \text{ k}\Omega$. The ink trace thus corresponds to subject resistance values of $100 \text{ k}\Omega$, $101 \text{ k}\Omega$, and $102 \text{ k}\Omega$ where the pen deflection was adjusted to 0 center for the $101 \text{ k}\Omega$ value. The switch remains on each step an equal length of time and this time is called the dwell time. It is adjustable and may be preselected over a range from less than 0.1 seconds to as long as 10 seconds.

The stepping switch chassis is shown in the left portion of the photograph in Figure 33. The underside is shown in Figure 34. Figure 35 shows a schematic diagram of the circuit.

1
M

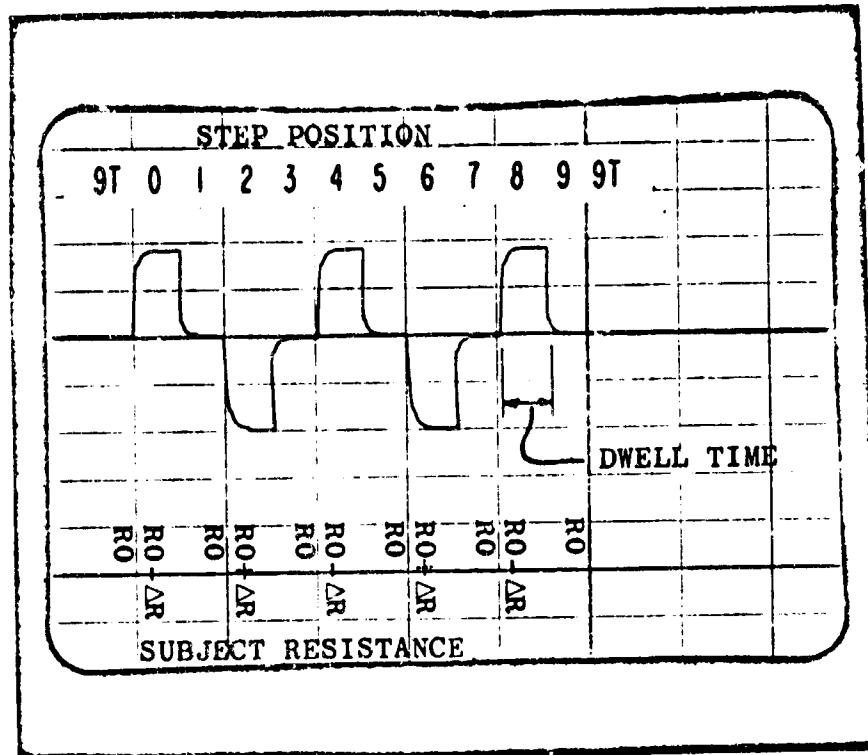


FIG. 32 EXAMPLE OF PROGRAMMING AUTOMATIC STEPPING SWITCH

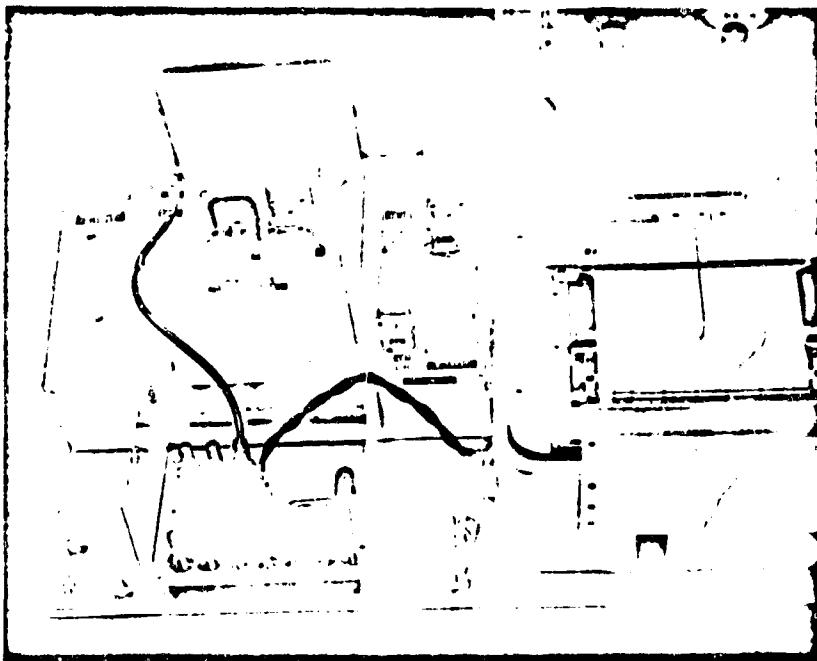


FIG. 33 PHOTOGRAPH OF INPUT EQUIPMENT

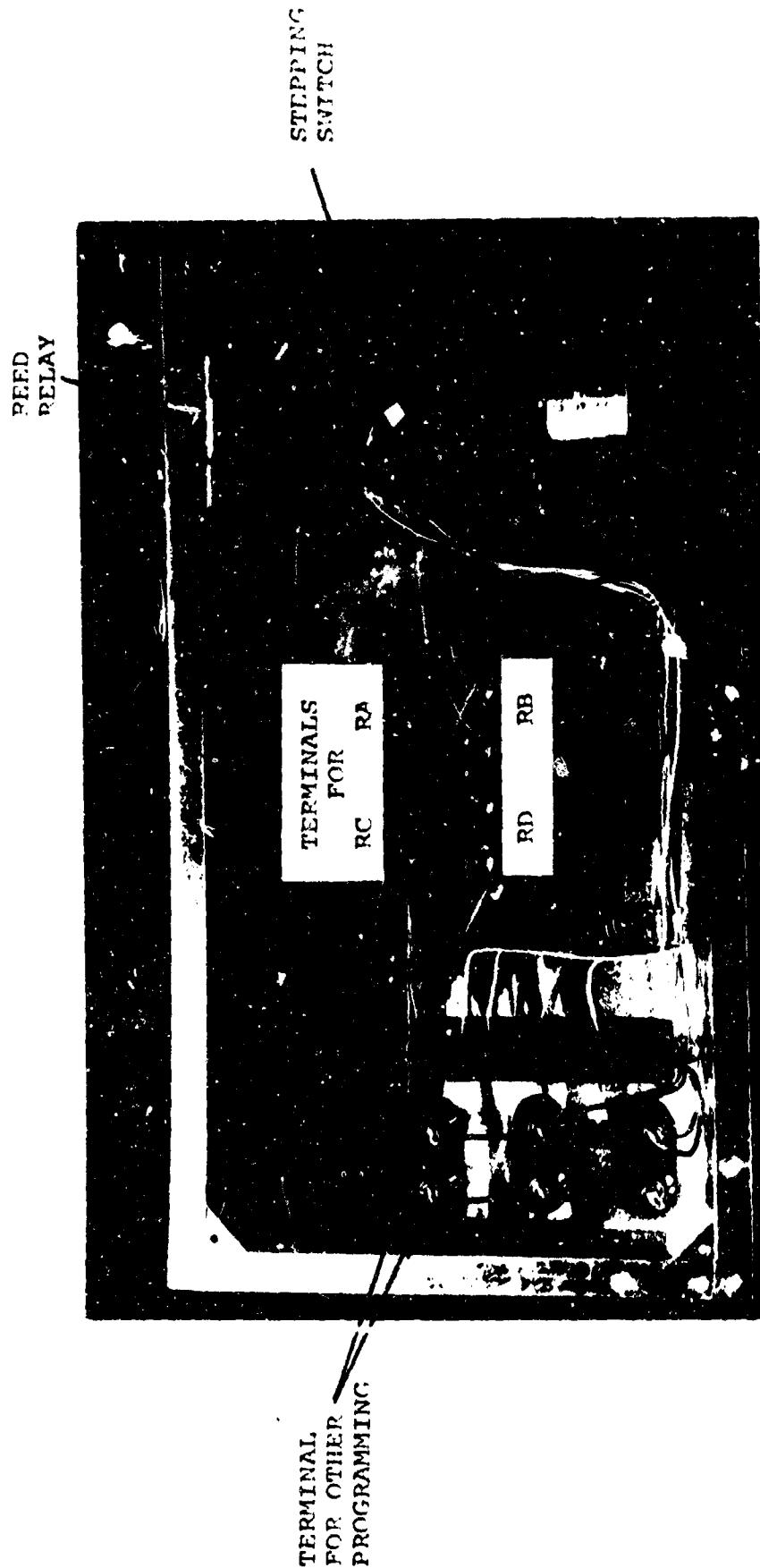
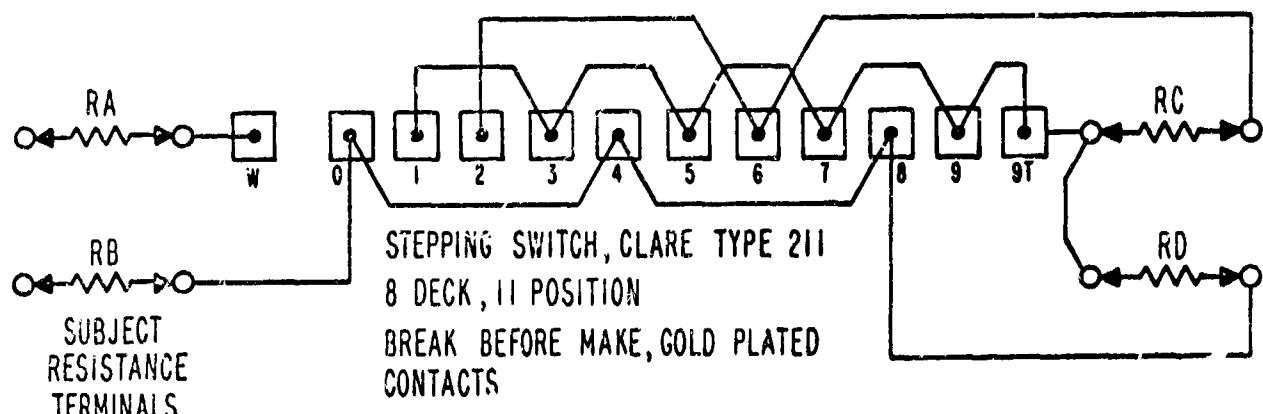


FIG. 34 UNDERSIDE OF SWITCHING CHASSIS

WIPER

POSITIONS, DECK B



PROGRAM
FOR RB-RC-RD
SHOWN IN FIG. 32
 $R_0 = R_A + R_B + R_C$
 $R_0 - \Delta R = R_A + R_B$
 $R_0 + \Delta R = R_A + R_B + R_C + R_D$

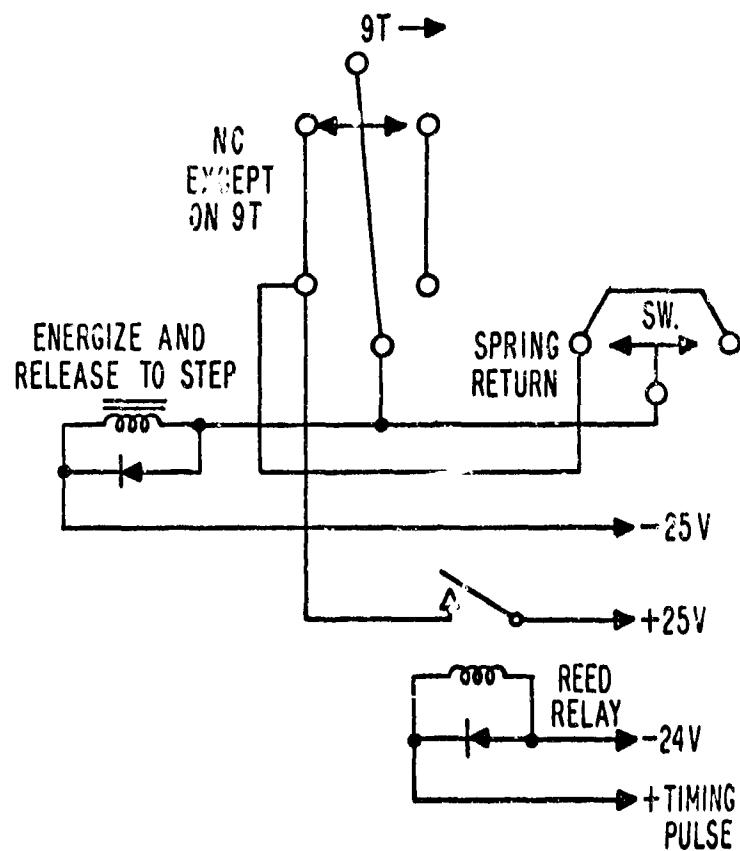


FIG. 35 SCHEMATIC DIAGRAM OF SWITCHING CHASSIS

TABLE III
List of Equipment

	Mfg.	Model	Serial	Block Diagram
Isolation Transformer	Stancor	P-6161	none	1,12,17
Power Supply	Tektronix, Inc.	160	395	2
Waveform Generator	Tektronix, Inc.	162	1574	3
Pulse Generator	Tektronix, Inc.	161	1089	4
Switching Chassis	NBS	--	--	5
Power Supply	Electronic Measurements	To 60 1.5M	2749	6
Battery (12 volts)	--	--	--	7
Voltage Divider	NBS	--	--	8
Attenuator Set	Hewlett Packard	350B	1171	9
Attenuator Set	Hewlett Packard	350B	1172	--
Attenuator	Hycor	303	none	10
Voltmeter	Hewlett Packard	412A	00402255	11
Function Generator	Hewlett Packard	202A	5176	13

TABLE III
List of Equipment (cont'd)

	Mfg.	Model	Serial	Block Diagram
Resistor (3.9 kΩ±1%)	--	--	--	14
AC-DC Precision Calibrator	Ballantine	420	101	15
Input Fixture	NBS	--	--	16
Variable Transformer	General Radio	V5	none	18
AC Line Regulator	Sorensen	1000S	1-2455	19
Expanded-Scale Voltmeter	Beckman Shasta	115	105 Lot 1	20
Voltmeter	Ballantine	302C	2034	21
Precision Resistors	General Radio	500	none	22
Oscilloscope	Tektronix, Inc.	545	9444	--
Plug-in-unit	Tektronix, Inc.	D	017501	--
Timer	GraLab	171	none	--
Calibration Timing	(WWV, derived)	--	--	--

ORGANIZATION ADDRESS	Unclassified
Institute for Applied Technology National Bureau of Standards Washington, D.C. 20234	N/A

10. REPORT TITLE

MECHANICAL AND ELECTRONIC EVALUATION OF TWO COMMONLY USED POLYGRAPH INSTRUMENTS

4. FINAL Report dated 31 March 1967

5. AUTHOR(S) (First name, middle initial, last name)

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13. ABSTRACT

Present evaluation would be limited to investigation of response to physical inputs: pressure signals in the case of the cardiograph sections; pressure and displacement signals in the case of the pneumograph sections; and pure resistance variation signals in the case of the galvanic skin resistance sections. The question of whether these physical variables represent accurately the physiological variables that are the normal inputs into the instruments is beyond the scope of the investigation and, in particular, no judgment is implied in the findings regarding the performance capabilities of the instruments for the purpose for which they are intended.

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KEY WORDS	LINK A		LINK B		LINK C	
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(PAGE 2)

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